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BERMUDA DURING THE ICE AGE.

With Thirteen Plates and Eighteen Text Figures.

By Robert W. Sayles.

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(Read by title October 14, 1931.)

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INTRODUCTION.

Inception of the Theory.

In March 1923, I visited Bermuda for the first time. Although this was primarily a vacation trip, a casual study of the geology was made. Very soon two facts forced themselves upon my mind. One was the luxuriant vegetation at present, the other the tremendous amount of dune formation in the past in contrast to the almost total absence of dunes now forming. I was also puzzled to understand how such great dunes could develop on such a small island, only 19 miles long and averaging less than 2 miles wide.

During the last few days of the stay at St. George's, I noted a deep red stratum eighteen inches to two feet thick intercalated between eolian limestones. Further study convinced me that this was an ancient buried soil, for it had all the essential characteristics of a soil and had many fossil terrestrial gastropods. It could be called a fossil soil. Such a soil, with thick eolian limestone below and above it could not form unless there had been a long interval between two periods of dune formation, an interval measured probably by thousands of years. Was it possible that the dunes below and above this fossil soil had formed when the island was larger and perhaps during a time of stronger winds? I did not know then, anything whatever of the literature on Bermuda, and of course was ignorant of the fact that Verrill and others had recognized the necessity of a larger Bermuda to account for the dune formation, due to uplift of the islands.

In reflecting upon the present small size of Bermuda, it was natural

to conclude that Bermuda must have been larger at one time and had subsided. A subsidence of sixty feet would change the area from about two hundred square miles to the present size of about twenty square miles. As I was very familiar with the glacial control theory of coral reefs advanced by Daly, it was most logical to explain a raising of water-level by deglaciation of the Pleistocene ice caps. It was at this point in the reasoning that it occurred to me that the buried soil I had seen and puzzled over might mean an interglacial episode of the Pleistocene, when the position of sea-level and the type of climate would be very different presumably from that existing during a glacial age, and would be more like conditions existing today. On the other hand, while the northern continents were buried under ice the climate of Bermuda ought to be stormier, and probably colder than the present climate, and furthermore Bermuda should be larger, due to subtraction of water from the oceans, and a larger Bermuda would explain the great dune formations better than the smaller Bermuda of today. A colder Bermuda would also reduce vegetation and this in turn would aid dune formation. During such a time soil formation might be very much restricted if not entirely prevented.

If the fossil soil found really meant an interglacial interval, there should be more than one, but there was no time left to investigate further. On my return to Boston I read one of Verrill's[1] papers on Bermuda and found that he spoke of several fossil soils in the eolian limestones. This encouragement made it possible for me to present a brief paper before the geologists at the meeting of the Geological Society of America in December, 1923.

History of the Field Work and Acknowledgments.

With the realization that there were several distinct fossil soils in the formations at Bermuda, it was evident that a study of the paleontology of the soils might make it possible to distinguish each soil. With this thought in mind, I invited Dr. Thomas H. Clark, now of McGill University, to accompany me to Bermuda in January 1924. We had just nine days of field work during this visit, but in that time found over fifty fossil soil localities and at least three and possibly four distinct soils in several places. We presented a brief paper to the Geological Society of America in 1925. In 1926 we visited the islands again for another short field trip of two weeks during the

[1] A. E. Verrill. The Bermuda Islands, Part IV. Trans. Conn. Acad. Arts and Sciences, Vol. 12, June, 1905.

latter part of May. Clark has made a number of contributions to the investigation. He discovered many of the fossil soil localities and recognized the importance of accretion, or addition to soils by wind action, in the formation of the lighter colored soils. Clark studied the collection of fossil snails and submitted to me a list of the fossils found in each locality.

In April, 1928, Professor Kirtley F. Mather of Harvard University, visited Bermuda with me. He contributed to the problem in several ways, but especially in finding marine fossils in the two important marine formations. In August of the same year Professor A. C. Swinnerton of Antioch College visited Bermuda to make a study of the caves. This study, together with his general observations on the geology, have been of much value in corroborating my own observations on several points as well as adding to our knowledge. In 1929, during March and part of April, I visited Bermuda accompanied by my family and made a more thorough study of the geology. It was during this visit that I met Professor Charles Schuchert of Yale University and was able to show him the formations in several parts of the islands, and to convince him of the reality of the different formations. Professor Schuchert made collections of fossils, especially of the fossil snails, and also aided me in many other ways. In November, of the same year, Professor R. A. Daly accompanied me to Bermuda and we saw a great deal of the islands in a few days, and discovered more fossil soil localities.

I am greatly indebted to many who have not been to Bermuda with me. First of all I wish to express my gratitude to Assistant Professor Marland P. Billings of Harvard University, who has edited the manuscript with much skill. In addition he has brought up to date the correlation of the Bermuda formations with the Pleistocene formations of North America and also added a chapter on the planation of the Bermuda group in the late Tertiary or early Pleistocene. At a time when unavoidable responsibilities made it impossible for me to revise and edit the paper, his help is deeply appreciated.

I wish to express my gratitude to Professor Emeritus E. L. Mark of Harvard University for aiding me from the very beginning of the problem, but especially for advising me to investigate the quarry at Shore Hills in St. George's. Mrs. R. D. House, formerly of the Harvard Mineralogical Laboratory, made several chemical analyses of the soils. The petrology of the soils and eolianites was done by Professor Esper S. Larsen of Harvard University and more than fifty analyses were

made, a long and arduous undertaking. For the time and thought he has given to this problem I cannot give enough credit. A study of the foraminifera found in the fossil soils was made by Professor Joseph A. Cushman of Harvard University. A study of the foraminifera in the eolian formations below and above the fossil soils was made by Mr. Lothrop Bartlett at Professor Cushman's laboratory, at Sharon, with important results. Professor Cushman also reëxamined the samples from the deep boring made at Bermuda in 1914, and came to conclusions different from those arrived at from the first examination made many years earlier. Dr. M. A. Howe, of the New York Botanical Garden, examined the marine algae found in a few of the fossil soils. Professor Leon W. Collet, of the University of Geneva, Switzerland, visited Bermuda in December 1926, alone, and was favorably impressed with the theory outlined in this paper. I wish to express my thanks to Mr. Freemont Rider, Editor of The Rider Press, Incorporated, for permission to copy in part the outlines of the map in their guide book. Mr. Edward A. Schmitz has skilfully made the soil map and cross sections.

Previous Geological Work.

After returning from my first visit to Bermuda in 1923, I studied the literature on the geology of the islands. I discovered that others had made observations similar to mine, but no one had considered the possible relation of glaciation to the evolution of Bermuda. The first real contribution to the geology of Bermuda was published by R. J. Nelson (*1840*). He made a distinct advance in demonstrating that modern Bermuda is composed largely of wind-blown fragments of shells and is not a true atoll. Papers by J. J. Rein (*1870* and *1881*), and Sir Wyville Thomson (*1877*) should be mentioned. W. N. Rice (*1884*) saw the necessity of a greater Bermuda to explain the great eolian deposits. He assumed a former higher stand of the island in contrast to the idea of the lowering of sea-level adopted in the present article. The papers by J. W. Fewkes (*1888* and *1890*) and Heilprin (*1889*) appeared shortly thereafter. Alexander Agassiz (*1895*, p. 220) doubted the need of appealing to subsidence or elevation. "Whenever the accumulations from the reef were sufficient to build up a beach reaching the surface, all the conditions necessary for the formation of sand dunes existed and we need not call upon either a subsidence or an elevation to account for the existing condition of the Bermudas." A paper by Stevenson (*1897*) appeared two years later. The most im-

portant papers are those by A. E. Verrill (*1903* and *1907*). He recognized a basal Walsingham formation, composed of eolian limestones and red soils, a younger marine limestone, called the Devonshire formation, and the youngest of all, the eolian limestones and red soils, called the Paget formation. The present investigation confirms this stratigraphy in a general way, but the relations are much more complicated than Verrill supposed. He was also the first to describe and discuss the origin of the red fossil soils and went so far as to estimate the amount of weathering and length of time necessary for them to form. The paleontology is well described. Verrill states that many of the species of snails are now extinct, which suggested the possibility of developing a stratigraphic paleontology for Bermuda. Pilsbry's (*1888*) description of the fossil land molluscs should be mentioned, for although strictly zoölogical, it has formed the basis for later paleontological work. Pirsson (*1914*) has given an excellent description of the deep boring in the island. It proves the current hypothesis that the eolian limestones of Bermuda form a thin veneer a few hundred feet thick resting on a volcanic platform. I have already published four brief notes on the fossil soils of Bermuda. (Sayles, *1924*, *1926*, *1928* and *1930*.)

Topography.

The Bermuda Islands lie 675 nautical miles southeast of New York City. They are included within the rectangle bounded by N. Lat. 32° 14′ and 32° 24′ and W. Long. 64° 38′ and 64° 53′. Modern Bermuda consists of over 150 islands and islets grouped together in a great hook trending northeast-southwest (see Fig. 1). The total area is about 19¼ square miles. In general the islands consist of rolling hills rising from one to two hundred feet above sea-level. At present the islands are sparsely wooded, although locally the vegetation is very luxuriant.

There are no surface streams in Bermuda. The drainage is entirely underground. The valleys, therefore, are not the product of running water. They are in part true sink-holes, formed by the collapse of the roofs of caves, and in part residual depressions left by the construction of sand dunes. Some of the depressions are occupied by peat bogs, the most conspicuous of which are Devonshire Marsh and Pembroke Marsh. The peat in the former is forty feet deep. Modern sand dunes are rare, although drifting sand is present in the vicinity of Elbow Bay and also near Tucker's Town. (Stevenson, *1897*, pp. 99–101.) In both areas, however, there is evidence demonstrating that

the formation of these small, local dunes was the result of deforestation. From the descriptions given by Verrill (*1903*, part III, 26, pp. 181–210; *1907*, part IV, 23, pp. 107–113), as well as from the early records,

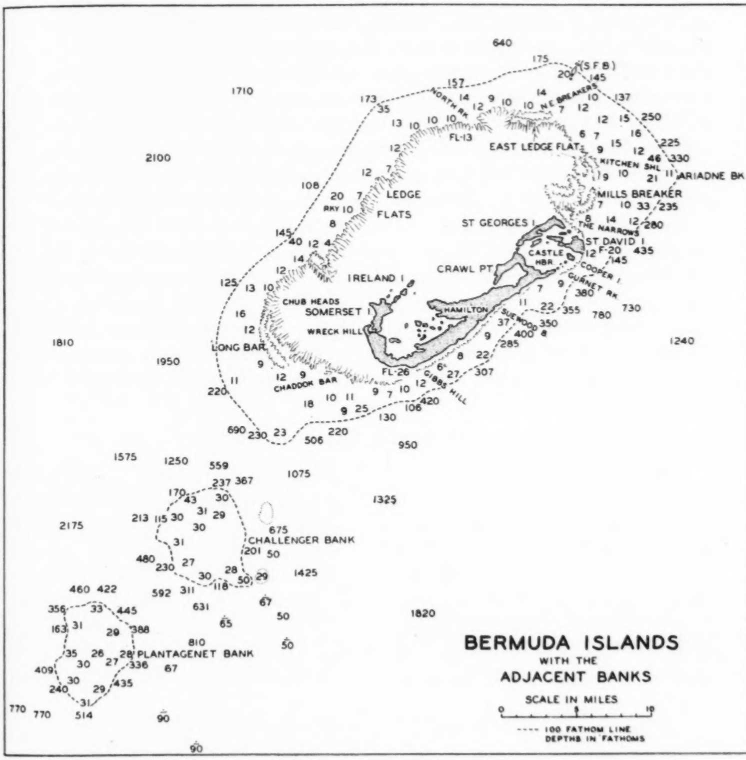

FIGURE 1.[1]

it is clear that before man invaded the islands they were heavily wooded and quite free from drifting sands.

The islands are perched on the southeast side of an elliptical sub-

[1] On account of the general use of the name "Argus" in the literature, the new name "Plantagenet" has not been adopted in this paper.

marine platform (see Fig. 1). The major diameter of the ellipse, trending northeast-southwest, is about 22½ miles; the minor, about 10½ miles. The total area is somewhat more than 200 square miles. Resting on this platform, the top of which is about 60 to 70 feet below sea-level, is an elliptical reef ranging in width from one to two miles. Its outer edge is from one to three miles inside the margin of the main platform. Most of this reef is submerged beneath very shallow water, averaging from ten to twenty feet in depth, but on the southeast side portions of the reef project above sea-level. Within the reef there is a lagoon in which the water is about sixty feet or less in depth. The configuration of this reef is thus suggestive of an atoll. As Verrill and others have pointed out, however, Bermuda is not a true atoll, for it is composed of eolian limestone. The corals and associated forms have contributed only a thin veneer. Beyond the edge of the platform the sea floor drops off rapidly to abyssal depths. The slope averages about 10 degrees and the surrounding ocean is about 16,000 feet deep (Fig. 2).

Fourteen miles to the southwest of the Bermuda platform is the Challenger Bank, the area of which is about twenty square miles and the depth approximately 180 feet. Still further to the southwest is the Argus Bank of similar size and depth.

IGNEOUS ROCKS.

It had long been supposed that the Bermuda platform is volcanic. The first proof, however, was obtained in 1912, when a deep boring was made in an unsuccessful attempt to obtain an adequate supply of fresh water for the Princess Hotel. L. V. Pirsson (*1914*) has fortunately recorded the data obtained from the well. Its site is in Southampton parish on the slope of a hill about a mile west of the Gibbs' Hill lighthouse. It began at an elevation of 135 feet above sea-level and was 1413 feet deep. The boring was made by churn drill and only powder and small grains were available for study. Pirsson gives the following section:

Eolian limestones—surface to 245 feet below sea level.

Brown, deeply weathered volcanics—245 feet to 455 feet below sea-level.

Sand and gravel of volcanic material—455 feet to 560 feet below sea-level.

Basaltic lavas—560 feet to 1278 feet below sea-level.

The petrography of the lavas was studied by both Pirsson and Thomas.[1] The dominant type is a melilite basalt, composed of micro-

[1] Pirsson quotes in his paper, already cited, a letter from Thomas.

phenocrysts of augite and altered olivine set in a groundmass of augite, melilite, apatite, analcite, biotite, magnetite, titanite, perovskite, nephelite, and sanidine. Although brown garnet is not mentioned, it is very probably present in small quantities, for, as will be pointed out later, it has been found in the fossil soils. A second group of lavas are of lamprophyric or monchiquitic types. The essential constituents are augite, biotite, and analcite; the minor acessories, perovskite and apatite. The groundmass is presumably nephelite, sanidine, and analcite, with such secondary minerals as titanite and calcite. Dr. Thomas[1] also reports one specimen of a keratophyre, in which microphenocrysts of albite and biotite are set in a groundmass composed of albite and microperthite.

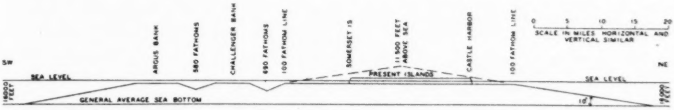

FIGURE 2. Cross section of Argus, Challenger, and Bermuda banks in a S.W.-N.E. line. (After Pirsson.)

The true interpretation to be given to the geologic section is still debatable. The presence of sand and gravel beneath the brown weathered volcanics implies that everything between the eolian limestones and the solid basaltic lavas is a product of subaerial weathering reworked by the ocean. It does not appear to be an autochthonous residual soil. Another problem concerns the depth of the igneous platform below sea level. If the boring is on the flanks of the platform, the surface is at some depth less than 245 feet below sea level, but when all the factors are considered, it seems legitimate to assume that the surface of the igneous platform of Bermuda is about 245 feet below sea level.

The elliptical shape of the Bermuda platform suggests that the volcano had at least two vents aligned in a northeast-southwest direction. The Challenger and Argus banks lie on a similar trend line and are the eroded stumps of two volcanoes. At some time in the past, therefore, Bermuda was the site of a line of volcanoes. They are certainly pre-Pleistocene and may be pre-Tertiary. Cushman informed Pirsson that certain foraminifera brought up in the drilling were Eocene and the latter concluded that the volcanoes were pre-Tertiary. Cushman has kindly reëxamined the material at my

request and now feels that the foraminifera are more likely Miocene or later.

SEDIMENTARY ROCKS.

Rock Types.

Reposing on the igneous platform of Bermuda are the calcareous sedimentary formations. The dominant type is an indurated eolian limestone. In my 1929 paper I proposed the name *eolianite* for all consolidated sedimentary rocks which have been deposited by the wind. If the rock is composed largely of calcareous material it would be termed a *calcareous eolianite;* if of quartz grains, a *quartz eolianite.* The Bermuda rock is thus a calcareous eolianite. In addition there are fossil soils, marine organic limestones, "sand-rock," and various present-day deposits such as calcareous ooze, beach sands, and dunes.

The Bermuda *eolianite* is a white or cream-colored, wind-deposited, more or less consolidated, rock composed chiefly of fragments of calcareous shells. The individual fragments vary greatly in shape. Most of them are rounded, others sub-angular, and still others very angular. The average size is half a millimeter, but the grains range in diameter from a tenth of a millimeter to two millimeters. Pelycepods have supplied most of the material, but foraminifera, crabs, and algae are also present. The eolianite is almost invariably cross-bedded, although in the more indurated varieties this is sometimes difficult to observe. The degree of induration varies greatly. The younger formations are loosely cemented, but the older ones are commonly compact and crystalline. Proximity to the present surface is also a controlling factor. In quarrying operations, after a thin veneer about 15 feet thick of relatively compact eolianite has been removed, the poorly cemented sands are encountered. After roads are cut down into the unconsolidated sands, rapid induration sets in and a compact eolianite soon develops.

The *fossil soils* are considered at much greater length in a later chapter. A few words, however, are necessary at this point. The soils vary greatly in physical and chemical composition. Most strikingly they are a deep-red or chocolate-brown color, but they are often pink or even cream-colored and sometimes gray. The former are composed largely of silica, alumina, and ferric iron; the latter are highly calcareous. Ordinarily the soils are only a few inches thick, but locally they fill great pockets in the underlying eolianite and may attain at maximum a thickness of twelve feet or more. Fossil snail shells are abundant in the soils, particularly those of lighter color.

Two processes are involved in the formation of the soils. One is long-continued weathering, which leaves the insoluble residue of the eolianite as a soil. A second process is the deposition by the wind of a finely pulverized material. After the deposition of such material it may be more or less deeply weathered. In any particular soil either one of the two processes may predominate. The absence of any evidence of earthworms, ants or other soil mixers would indicate that the making of these Bermuda soils was different from that which prevails on the mainland.

A *soil-base,* described in greater detail on a later page, is frequently present beneath the fossil soils of Bermuda. It is usually from ½ to two inches thick and is a compact, subcrystalline, cream-colored limestone.

The marine organic limestones are composed of well-cemented marine shells and fragments of shells.

Collophanite ($CaO \cdot P_2O_5 \cdot CO_2$), a product of guano, is found on Stokes Point (see p. 401). It is a hard, fine-grained grayish rock resembling quartzite.

Stratigraphy.

Stratigraphic Column. In the course of the present investigation the following stratigraphic column has been established. Due to the eolian nature of the deposits, overlaps and unconformities are abundant. In many sections some of the formations may be completely lacking. These relations are brought out in the structure sections (see Figs. 6, 7, 8, 9, 10, 11, 16, 17).

TABLE I. Stratigraphy of Bermuda.

Present soil	Usually gray or light-colored pink soil; red in small pockets.
Southampton eolianite	White loosely consolidated eolianite; compact only near surface.
McGall's soil	Mainly a light-colored calcareous soil of accretion; red only locally.
Somerset eolianite	White loosely consolidated eolianite; compact only near surface.
Signal Hill soil	Gray to pink soil, in large part due to accretion.
Warwick eolianite	White loosely consolidated eolianite; compact only near surface.
St. George's soil	Thick deep-red soil in depressions; pink to red on slopes; from ½ foot to two feet thick; a soil of weathering.

Pembroke eolianite	White to cream-colored eolianite; not as compact as Walsingham, but better consolidated than the younger eolianites.
Harrington soil	Light-colored to red soil, four feet thick at maximum; mainly a soil of accretion.
Devonshire limestone	Loosely consolidated or compact organic limestone composed of marine mollusc shells and a few corals.
Shore Hills soil	Deep-red or brown soil from one to four feet thick; mainly a residual soil.
Belmont limestone	Compact limestone composed mainly of marine mollusc shells.
Walsingham eolianite	Usually a cream-colored compact crystalline eolianite; in places loosely consolidated.
(Great unconformity)	
Volcanic platform	Melilite basalt, monchiquite, and keratophyre flows. Also altered volcanic material deposited in the sea.

Walsingham eolianite. A. E. Verrill (*1907*, p. 24) proposed the name Walsingham formation to designate that portion of the older Bermudian strata of limestone and red clay characterized by containing several species of extinct land snails, of which the largest and most abundant is *Poecilozonites nelsoni*. I propose to re-define the term Walsingham so as to restrict it to the eolianite beneath the Belmont marine limestone. As thus re-defined the Walsingham is a compact, crystalline eolian limestone in which the cross-bedding is commonly masked by induration and re-crystallization. Locally it is loosely consolidated. The formation may be seen to best advantage in the Government Quarry at Paynter's Vale, on the west shore of Castle Harbor (132),[1] where the rock is a compact crystalline eolianite. It is also found in all the caves in the type locality, the Walsingham district, which is the isthmus separating Castle Harbor from Harrington Sound. The stratigraphic relations of the Walsingham formation with the overlying horizons may be seen best along the stretch of road extending for half a mile west of Shark Hole (123). Other localities are Tucker's Town Cave (131), Tucker's Island (130), Crystal Cave, Walsingham Cave, Leamington Cave, and other caves in the Walsingham district.

Belmont limestone. (Fig. 6, 7, 8, and 9.) The Belmont limestone is

[1] Numbers in parentheses refer to the locality numbers on the map, Plate XIV.

a compact, cream-colored, marine formation, composed dominantly of well-preserved mollusc shells and some foraminifera. Rounded eolianite grains are common. The type locality is a quarry on the Shore Hills Hotel golf course (89). About 15 feet of gently inclined marine strata are exposed. The top of the formation is about twenty-five feet above sea-level, but the base is not exposed. Overlying this marine limestone is the Shore Hills soil. Other localities where the Belmont limestone may be seen are: Grape Bay (130), Wilson's Island (129), Hinson Island (105), Marshall Island (104), Hotel Inverurie (102), Belmont Hotel (37), McGall's Bay (69), Stokes' Point (24), and possibly Ruth's Point (60), Mullet Bay (10), and Surf Bay (21).

Shore Hills soil. (Fig. 5, 6, 7, 8, 9, 14, 17.) For the fossil soil lying stratigraphically above the Belmont limestone, I propose the name Shore Hills from the type locality at the quarry on the Shore Hills golf course, now the property of the Bermuda Biological Station for Research, Inc. This is the thickest fossil soil in Bermuda. It is deep red in color and averages four feet, in some pockets at least twelve feet, in thickness. This formation is also well exposed at Grape Bay (130), where it rests directly on the Belmont marine limestone. Much of the soil at the latter locality has been destroyed by recent erosion, but the deep solution-pockets in the marine limestone are filled with the fossil soil and demonstrate a long interval of weathering. The deep cylindrical solution-pockets projecting downward into the limestone have been called "palmetto stumps" by the natives, on the assumption that they are the casts of stumps of that tree. Wherever such forms are found they may be used as evidence of the former presence of a fossil soil. Other localities where the Shore Hills soil is found are: Hinson Island (105), Marshall Island (104), Darrell Island (128), Hotel Inverurie (102), Belmont Hotel (37), marine bench to the west of the McGall's Bay locality (69), "palmetto stumps" at Spanish Rock (13), and possibly the fossil-soil horizon just above the cave at Tucker's Island (127). The lower soils at Surf Beach (21) and Ruth's Point (60) may be of this age.

Devonshire limestone. (Fig. 17.) A. E. Verrill (*1907*, p. 32) proposed the name Devonshire formation (from Devonshire parish) for the marine limestones, or, as he called them, "beach-rocks." He recognized only one such horizon, but it is clear that there are two, one above, the other below the Shore Hills soil. For the marine limestone beneath the Shore Hills soil I have already introduced the name Belmont. I propose to restrict the term Devonshire to the marine

limestone overlying the Shore Hills soil. The type locality is at Devonshire Bay, where the formation is exposed under the cliffs in front of the old fort site. The lower portion belongs to the Belmont formation and is composed of compact, creamy, organic limestone rich in pelecypod shells. Resting unconformably on this lower member is the Devonshire formation, a conglomerate several feet thick, composed of flat pebbles four or five inches long. Although the Devonshire formation is well indurated at the type locality, it is frequently only loosely consolidated, as at Hungry Bay (133). At Stokes Point, the fossil corals which are present in the limestone, suggest climatic conditions similar to the present. The formation is also exposed at McGall's Bay (69), Spanish Rock (13), Elbow Bay (50), Stokes Point (24), western end of Pink Beach (107), and possibly Surf Bay, Ruth's Point, and Mullett Bay (10).

Harrington soil. (Fig. 8, 10, 14, 16, 17.) For the fossil soil developed directly above the Devonshire marine limestone I propose the name Harrington, from the type locality on the southeast shore of Harringon Sound just west of Shark Hole (123) where it may be followed for several hundreds yards on the north side of the road until it reaches sea-level. About one hundred feet farther to the west the "palmetto stump," indicative of the Shore Hills soil, may be seen. The Harrington soil at this locality is light colored, four feet thick in places, and composed of wind-blown materials, greatly weathered in some places but fairly fresh in others. The Harrington soil thus differs greatly from the Shore Hills soil. The former may be largely a soil of accretion, the latter a soil mainly of weathering. The significance of this fact is discussed on later pages. The extinct land snail *Poecilozonites nelsoni* and many other species of snails are abundant. Other localities are McGall's Bay (66–78), Devonshire Bay (79–81), Hungry Bay (133), Grape Bay (130), Elbow Bay (50), Hinson Island (105), Wilson's Island (129), both sides of Pembroke Marsh, north of Hamilton (93), and probably most of the low-lying fossil soils around Hamilton (56–58). Some of the fossil soils northwest of Hamilton probably belong to the Harrington. It is also possible that the Shore Hills and Harrington soils have locally merged into one, as at Hinson Island. Along the north shore some of the soils appear to be of this age, for example the Shelly Bay racecourse (61), Cottage Hill (19), Bailey's Bay (20), Mullet Bay (10 and 11), Ruth's Point (60), and Sandys Parish (46 and 121).

Although the fossil land snail *Poecilozonites nelsoni* is not always

present in the Harrington soil, it has not been found in any higher horizon. Along the south shore this species has been recognized only at Spanish Rock. Some of the fossil soil outcrops inland may be of Pembroke age, but at the present moment definite data are lacking.

Pembroke eolianite. (Fig. 6, 7, 10.) For the eolian limestone overlying the Harrington soil the name Pembroke is proposed because of its abundance in the parish of that name. The type locality is on the east end of Reid Street, Hamilton, near the junction with East Broadway, and about one hundred feet south of the livery stable (57). At the base of the section is a compact eolianite, probably the Walsingham. The deep-red soil over this is assigned to the Harrington-Shore Hills, above which is the Pembroke eolianite. A deep-red soil overlying the Pembroke can be seen in a cliff near the east end of Reid Street (58). This probably represents the interval of time from the Pembroke to the present. On the Middle Road the relations of the soils and eolianites are excellently exposed. Nearly all the islands in Hamilton Harbor, Great Sound, and Little Sound are capped by Pembroke eolianite. Other localities are Wilson's Island (129), St. George's (3 and 4), McGall's Bay (69), Devonshire Bay (79), and Hungry Bay (133). Locally the Pembroke is absent, as at Elbow Beach (50) and Grape Bay (130).

St. George's soil. (Fig. 3, 6, 7, 10, 11, 12, 13.) The term St. George's is suggested for the fossil soil overlying the Pembroke eolianite. The type locality is on Ferry Road, St. George's (1), where it has a deep-red or chocolate-brown color and at a maximum is two feet thick. The St. George's soil is also well exposed at McGall's Bay (68), Simmons Beach (108), Elbow Beach (50), Hamilton (25), in the new cut on Eliot Street in Hamilton, and at the four corners on the Paget-Warwick line (113).

Warwick eolianite. (Fig. 3, 7, 10, 13.) For the eolianite overlying the St. George's soil, I propose the name Warwick. The type locality is in the parish of Warwick. It may also be seen at McGall's Bay (68), Simmons Beach (109), Elbow Bay and other places. On the road to Gibbs' Hill light it is probably the eolianite between the two soils on the west side of the road. The Warwick eolianite is a white to cream-colored, loosely consolidated eolianite. It is indurated for only a few feet below the surface.

Signal Hill soil. (Fig. 7, 10.) This name is proposed for the soil overlying the Warwick eolianite, from the type locality at Signal

Hill, St. George's (5), where it is pink and about two feet thick. Throughout the islands as a whole it is a soil of accretion, although in local pockets the products of residual decay have accumulated. The Signal Hill soil may be well seen at McGall's Bay (69), Simmons Beach (109), Elbow Beach (50), and at Khyber Pass (33).

Somerset eolianite. (Fig. 7, 10, 12.) For the eolianite overlying the Signal Hill soil, I suggest the name Somerset from the village of that name in Sandys Parish. As a rule it is white to cream-colored, thin, and loosely consolidated. Only near the surface is it well cemented. Dr. Thomas Clark first recognized it as a distinct formation in 1926 at McGall's Bay, where it lies in the Signal Hill soil (69). It has also been found at St. George's (6) and at Simmons Beach, and other places.

McGall's soil. (Fig. 4, 7.) This name is proposed for the soil overlying the Somerset eolianite. The type locality is at McGall's Bay, but it has also been found at St. George's (6), Elbow Bay (50), and Simmons Beach (56). It is very similar in appearance to the Signal Hill soil. It is usually very light-colored, although in local pockets it may be rather pink. This soil is largely a product of accretion rather than of decay.

Southampton eolianite. (Fig. 4, 7, 10.) The Southampton eolianite, named from the parish of that name, does not differ essentially from the Somerset eolianite. Both are white, loosely consolidated eolianites, being cemented into a compact rock only near the surface. The Southampton is well exposed at McGall's Bay (69), St. George's (6), and Simmons Beach (108). It undoubtedly [illegible] in numerous other localities.

Recent soil. (Fig. 5, 6, 7, 10.) The recent soil, developed since the deposition of the Southampton eolianite, is comparatively thin. It is gray to brown in color. On level ground it is not more than six inches thick, which conforms with the thickness of post-Wisconsin soils in the limestone regions of the United States under similar topographic conditions. On hill-sides the soil may be completely lacking. The recent soil may be seen on the golf course at St. George's (6), at Shore Hills (89), where it is developed on the Pembroke or later eolianite, at Spanish Rock, and many other places.

In speaking of the recent soil it must be noted that the deep soils in many places are the result of weathering for a much longer time than the post-Wisconsin or Recent episode. In many places dune formation has not gone on for a very long time. For example, in

much of the Walsingham district, where the Bermuda caves are mostly located, dune formation has not gone on since the Harrington or Pembroke stages. In many depressions the surface soils are very thick, and it is in such places that the productive truck and flower gardens are found. The thick soil in low land or depressions is the result of long weathering and also of the wash of rains, which carry weathered materials to lower levels about as fast as they are formed on the slopes. Earthworms do not seem to have played any part in the formation of the fossil soils of Bermuda. At least there is no evidence in the soils that they existed. The common earthworm, *Lumbricus terrestris*, evidently did not find its way here. Whether or not there were ants, we do not know.

Sand Dunes. Modern sand dunes have been discussed in the section dealing with the topography of Bermuda.

Type Localities and Special Areas.[1]

The stratigraphic relations of the eolianites and fossil soils of Bermuda are best displayed at St. George's, McGall's Bay, and on the Warwick-Paget line. These localities will therefore be described in considerable detail, in order to demonstrate the stratigraphic column already given. A brief description will also be given of the sedimentary rocks in the Hamilton region, the Walsingham cave district, and some of the islands.

St. George's. St [illegible]eorge's parish may well be considered the type locality of the f[illegible]ils of Be[illegible]uda. Four of the five soils are exposed [illegible] as to preclude any possible doubt that each so[illegible]nts a distinct and separate horizon. About 300 feet west of a residence on Ferry Road called "Glen Duror" the Harrington soil may be seen on the north side of the road near the level of the gutter. It is about two feet thick and of a light color. No fossils were found. It is covered by Pembroke eolianite which evidently came from an easterly direction, as indicated by the dip of the cross-bedding. On the same road several hundred feet east of Glen Duror the St. George's soil is exposed in the cliff on the north side of the road

[1] It is desirable to place on record a detailed description of the many localities upon which are based the conclusions reached in this paper, particularly for the benefit of geologists who may visit Bermuda in the future. Many of my readers, not being interested in the details of Bermuda geology, may prefer to omit these long descriptions and pass at once to the section entitled "Fossil Soils."

(Fig. 3). Here it has a deep-red or chocolate color, characteristic of residual soils. It is two feet thick at maximum. This soil has no complete fossils here, but toward the east it rises at a small angle, becomes lighter in color, and encloses many snails. Erosion has cut it off at a point about one hundred yards east of the deep-red part of the exposure. West of the locality first mentioned, where the soil is so red, it may be followed in the cliff for several hundred feet. This soil is clearly younger than the Harrington. The Warwick eolianite, which overlies the St. George's soil, appears to have come from the north.

Leaving Ferry Street near the eastern limit of the exposure of the St. George's soil and going up Signal Hill by the pass, the Signal Hill soil may be seen near the top of the pass. It dips north and is plainly a higher soil than the St. George's, for the Warwick eolianite intervenes. The soil has a pale color, is about two feet thick, and slopes to the north. Fossils are plentiful in both exposures on either side of the pass. Vegetation must have been thick enough to protect it from rain-wash, for no soil could form at such an angle unless it was so protected. The overlying eolianite, which seems to have come from the north, is the Somerset.

A still higher soil, the McGall's, may be seen at a number of places around Signal Hill, but the best locality is on the golf course (6) about two hundred yards northeast of the locality last described (Fig. 4). It is a moderately consolidated, dark layer about a foot thick, overlain by several feet of Southampton eolianite, which in turn is overlain by the recent soil. The McGall's soil at this locality is full of fossils and carries fragments of carbonized wood. On exposure to the air for a few months this soil becomes so hard that a hammer is required to break it. Because of deforestation at St. George's in the early days, when St. George's was the principal settlement at Bermuda, the recent soil has been completely eroded in most places. The resistant soil base, however, has protected the underlying eolianite. From this instance we may conclude that when the fossil soils were forming, vegetation must have flourished, for otherwise no soils could have formed on the hill slopes.

The important Stokes' Point (24) and Shore Hills (89) localities, are also included in the St. George's area. At both of these places the Belmont, Shore Hills soil, Devonshire marine formation, and Pembroke eolianite are found. The Harrington is not a distinct formation at Shore Hills, and at Stokes' Point it is uncertain.

No geologist who has visited Stokes Point has come away satisfied

FIGURE 3. Deep red phase of the St. George's soil at St. Georges. Thickness 18 inches to 2 feet at deepest parts. Photo. by author. Locality 1.

FIGURE 4. The McGall's soil at St. George's. Note the transition beds above the head of Professor Schuchert, and the dune structure of the Southampton eolianite lying on the transition beds. The soil is very compact and when exposed to the air for a short time can be broken only with a hammer. Many individuals of *Poecilozonites bermudensis* var. *zonatus* were found and a number of fragments of carbonized wood. Photo. by author. Locality 6.

as to just what has happened there. It is still an unsolved problem. The underlying rock here is a reddish, very compact crystalline limestone. An examination of a thin section of this rock shows it to be composed of well-rounded calcareous grains of foraminifera. Both the eolian grains and the foraminifera are much decomposed. The decomposition is so great that I have concluded that this underlying rock, which I correlate with the Belmont, has been exposed to the air for a long period of time and might almost be called a soil. If so, it is part of the Shore Hills soil and the overlying rubble soil must be Harrington. This soil lying on the red rock is about 18 inches thick near the water-level and decreases in thickness upwards in the cliff. Solution holes penetrate the red formation, but they are not deep as at other places where the Shore Hills lies on the Belmont. The soil itself has evidently been worked by the waves in its lower part. Fragments of the red rock, reaching a diameter of a foot, are found in it, and some of these also show solution cavities, as noted by Swinnerton. Marine shells are common in the lower part of the soil, but in the upper part there are no marine shells. Fossil land-snails are abundant in this upper part. Above the soil comes the Devonshire marine formation, with a plentiful assortment of marine forms including corals and pelecypods. The thickness of the Devonshire here is about five feet. Above the Devonshire comes the Pembroke eolianite.

There is a cliff at Stokes Point, where these geological relations can be seen. This cliff, about fifteen feet high, shows distinct evidence of a higher sea-level. It is hollowed out so as to produce what might almost be called a sea-cave. On the inside wall there is a mass of marine rubble, rounded pebbles, and marine fossils in a consolidated mass. That the sea has been at work here is evident. The old water-level is well shown about twelve feet above the present water-level. Among the ancient pebbles found at Stokes Point are some which are distinctly oölitic. The nature of this oölite has not been determined. There are also pebbles of a rock that looks very much like quartzite. Larsen analyzed this rock and found it to be collophanite, which is a phosphate rock containing in addition calcium, carbon dioxide and water.

If the red base-rock here is of Shore Hills age, and the soil lying on it Harrington, the Devonshire is younger than the Harrington. This does not fit the facts along the south shore and elsewhere. At Swing Bridge (12) there is a soil which has every appearance of being Harring-

ton in age, and this locality is only a short distance from Stokes' Point. Just what the relations at Stokes' Point are is not clear at present, but I believe the red rock is of Shore Hills age and the rubble soil with the marine and land forms to be a part of the Shore Hills soil, and that the rising water-level of Devonshire time was interrupted long enough to permit the development of the upper part of the soil containing the land forms. The level then rose again and covered the soil and the Devonshire marine limestone was laid down. Locally the Harrington appears to be missing. It may have been eroded by the winds which marked the advent of the Pembroke eolianite, for this took place at McGall's Bay, also locally. Stokes Point requires more study, and when correlations over the rest of Bermuda are more certain it will be possible completely to solve this difficult problem.

At Shore Hills, the type locality of the Shore Hills soil, there is much of fundamental interest. In the first place, the rock at the quarry on the golf course is a true marine formation of crystalline limestone containing many marine forms. These included fossils have been examined by Dr. Carlotta J. Maury, who finds none to be pre-Pleistocene. Verrill did not mention this formation, and, as far as I can discover, it has not been noted before. Shore Hills was off the main line of my first visits to Bermuda, and I am indebted to Professor Mark for suggesting that I visit this locality. I discovered at this time, in company with Professor Mather, that the formation contained many marine fossils. This is the highest known outcrop of the Belmont marine formation, and the highest marine formation at Bermuda. Fifteen feet of this Belmont is in sight (Fig. 5). On the Belmont lies the Shore Hills soil with an average thickness of four feet and pockets twelve feet or more deep. Above the soil lies an eolianite, four feet thick, which has an older appearance than the Warwick and later eolianites. It is thought, provisionally, to be Pembroke in age. On the Pembroke lies a more recent soil, the present soil. It is about a foot thick. Like some other parts of Bermuda this locality escaped much of the later dune action. The great thickness of the Shore Hills soil indicates, however, that there must have been a considerable thickness of rock at one time between the Shore Hills and the Belmont. The nature of this rock is not known. On account of this uncertainty the exact relations here await further research. The fossils of the eolianite above the Shore Hills soil indicate little. There is, therefore, a possibility that this may be one of the younger formations, and that the soil lying on it is entirely post-glacial in age.

FIGURE 5. The highly weathered soil at Shore Hills, St. George's, known in this paper as the Shore Hills soil. Average thickness above pockets 4 feet. Depth of pockets about 12 feet. Lies on Belmont marine limestone 25 feet above tide. Eolianite on soil, of Pembroke or later age. The thickness of the soil on the eolianite, about 1 foot, would suggest a length of time longer than post-Wisconsin, and the appearance of the eolianite itself suggests that it is one of the older eolianites. Fossils do not help in this case. Photo by A. C. Swinnerton. Locality 89.

It is most probable that in other parts of Bermuda this high marine formation lies buried under later eolianites.

The St. George's region was studied first and it is thought best to describe it first, inasmuch as it is the type region of the fossil soils, though logically the Stokes' Point and Shore Hills might well have been treated first. The main point to establish is that here there are undoubtedly five distinct fossil soils in addition to that now forming.

Surf Bay (21-22). At the west end of the beach at Surf Bay there is a bench of rock, the upper surface of which is about ten feet above sea-level. The upper part of the bench is composed of an indurated fossil soil which extends some distance up into the cliff and contains many shells of the larger species of *Poecilozonites bermudensis*. Near the top of the cliff there is another fossil soil about six inches thick with many fossils, mostly *P. bermudensis*, and in the sands just above this soil are more fossils of the same species. This upper soil is of a light color and fine grain. The lower soil is probably of Harrington age. The upper soil may be of St. George's age. This locality has not been visited since 1924 and no further details are available.

Pink Beach (107). At the western end of Pink Beach (Fig. 6) a thick fossil soil is seen just above the sands of the beach and in the cliff. The formations noted here occur as follows. The lowest formation is a marine limestone with many marine fossils. It is very compact, although much pitted by marine corrosion (see plate 10). The exact contact with the overlying soil is not visible. The soil is about two feet thick, about five feet above sea-level, red in color and carries many fossils, poorly preserved. The fossils are mostly land snails, but the species were not determined. There are also fragments of crabs in the mass. Above this soil comes eolianite, about five feet thick, and lying on this another red soil, about eighteen inches thick, with fossils, and divided formerly by a soil base. This soil base has been destroyed by weathering and only fragments are now to be seen, as proof of its former existence. Above the upper soil is a thin soil composed of fragments of rock, forming a kind of rubble, the recent soil.

It is supposed that the marine formation underlying this series is of Belmont age, that the lower soil is of Harrington or St. George's age, and that the upper double soil consists of St. George's, Signal Hill or McGall's soils. The uncertainty of the age of the lower soil makes any definite determination impossible at present. The age of the eolianite between the two soils cannot be definitely determined. By

the edge of the water there is a small stack of eolianite. It is firmly, but unconformably, connected with the underlying Belmont marine limestone. The base is as compact as the Belmont, while higher up it is much less resistant, showing the effect of marine conditions on consolidation. In general the shore-rocks close to the sea are very much indurated, while higher up they are much softer. There is no soil between this stack and the Belmont formation, and it has been concluded that the eolianite of this stack is younger than the forma-

FIGURE 6. Pink Beach in section, looking east.

1. Belmont marine formation.
2. Shore Hills-Harrington or St. George's soil.
3. Pembroke eolianite.
4. St. George's or later soil.
5. Recent rubble soil.

On the right a stack, the remnant of a late dune, the erosion due to a fairly recent higher stand of the sea. Locality 107.

tions noted above. I believe that it is the remains of a late dune which was formed and then submerged by the more recent rise of sea-level, and all but destroyed during this rise and fall of the sea. The marine pitting in the Belmont formation is noteworthy when compared with the much deeper pitting in the shore-rocks back of Walsingham House. It is evident to me that the uncovering or removal of dunes at Pink Beach, of which this stack is the last survival, is a fairly recent event, and that at Walsingham House there were no dunes to remove.

Albouy's Point (15–17). Here there is a problem which remains to be settled. In a quarry on the north of the road a deep-red soil appears about midway in the face of the quarry. The soil has many fossils, mostly *Poecilozonites bermudensis*. It is about a foot thick. The rock is a very much indurated eolianite both below and above the soil. Little

time was available for the collection of fossils, so, it is not known definitely whether or not the species *P. nelsoni* is here. This soil has every appearance of being the Harrington, or even Shore Hills soil, with Walsingham eolianite below the soil and Pembroke eolianite above. More study must be given to this important locality before anything very definite can be said.

Spanish Rock. One of the best places to see the relations between the Belmont, Shore Hills, and Devonshire formations is at the Spanish Rock locality (13). At the west end of Spittal pond, and among the rocks near the ocean may be seen the familiar "palmetto stumps" which so often locate the former position of the Shore Hills soil. The soil itself has been eroded away. In the cliff to the east, not over 30 feet away, is the Devonshire formation, which at this point is full of fossils. Above the Devonshire comes an eolianite. At this point the Harrington soil appears to be missing. However, on the ocean side, in the cliff at a point 100 yards or perhaps more to the east, there is a soil on a level with the floor of the sea-cave found there. This cave cannot easily be reached from the "palmetto" locality, on account of the steep cliff on the ocean front at this point. By going eastward, however, several hundreds of yards, a way can be found to the ocean and then it is comparatively easy to make one's way back toward the west, where the cave is found at about 15 feet above sea-level. At this point a single *Poecilozonites nelsoni* was found. It is concluded that this soil here is the Harrington. The erosion of the Harrington soil locally has been noted at McGall's Bay and at Stokes Point and it appears to have occurred also at this Spanish Rock locality. The importance of this locality (13) is evident. The close proximity of the Belmont and Devonshire marine formations in many places makes it difficult to distinguish between them. The Shore Hills soil is sometimes found between them but not always, and this is due to the erosion of the Shore Hills by the rising waters of the Devonshire. In places, as at Grape Bay, the Devonshire does not appear, but the Shore Hills and Belmont are excellently shown. In cases like this dunes must have covered the Shore Hills while the Harrington was forming in other places, and not until wave action had swept away the covering of the dune, many years later, was the Shore Hills again exposed to the air.

McGall's Bay (plate 7). The McGall's Bay locality (66–78) is the only place other than St. George's where four distinct fossil soils may be seen together. At the base of the exposed section is the Belmont marine limestone. On top of this a few isolated patches of Shore Hills

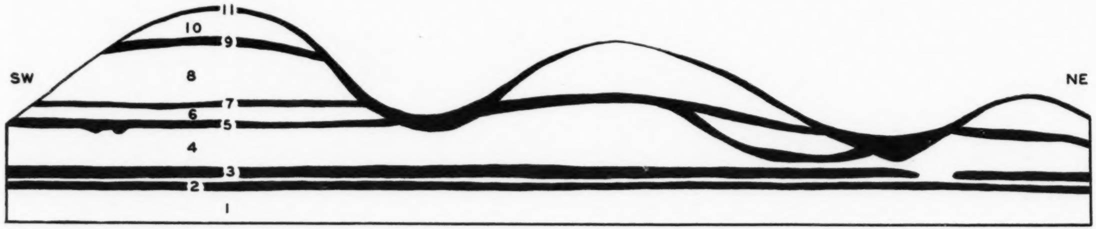

FIGURE 7. A rough field sketch of McGall's Bay section.

1. Belmont marine limestone.
2. Shore Hills soil (a patch only).
3. Harrington soil.
4. Pembroke eolianite.
5. St. George's soil.
6. Warwick eolianite.
7. Signal Hill soil.
8. Somerset eolianite.
9. McGall's soil.
10. Southampton eolianite.
11. Recent soil.

Localities 66–75 (Clark and Sayles).

soil suggest its former presence in greater quantity. About 100 yards west of the most westerly part of this exposure in the marine bench occur the "palmetto stumps," or solution holes, with remnants of an indurated soil as further evidence of the former presence of the Shore Hills soil. Above this is a slight thickness of sandstone and then the Harrington soil, which is relatively thick, clay-like in its constituency, and light in color. Next in the section is the Pembroke eolianite, which along this shore ranges in thickness from three to twenty feet. The overlying St. George's soil is red and varies from eight inches to a foot in thickness. Above this comes several feet of Warwick eolianite, and still higher the Signal Hill soil, which is red but only six to eight inches thick. The Somerset eolianite overlying the Signal Hill soil ranges from ten to twenty feet thick. Next is the McGall's soil, which is light in color, little weathered, full of fossils, and clearly a soil of accretion. It is only eighteen inches thick. At the top of the section is the Southampton eolianite, scarcely a foot thick, which is overlain by a few inches of recent soil.

Devonshire Bay (80–81). Starting at the water's edge under the cliff at the point, it is found that the lowest formation is a compact marine limestone, made up as usual of eolian sand grains and containing many fossils. Above the limestone, and lying unconformably on it, is a conglomerate made up of pebbles, presumably of the hard underlying limestone, and with a matrix of sand (See plate 8). Above the conglomerate is a formation of sandstone several feet thick. Lying on the sandstone and merging with it is a fossil soil of light color and fine texture and unconsolidated. There are numerous fossil snails in the soil, mostly of the species *P. bermudensis*. Above the soil is a thick eolianite formation dipping at an angle of 30° north. On both sides of the path which traverses the remains of the old fort there is a soil between two and three feet thick, of a deep red color, dipping about 20° southwards towards the ocean, and disappearing from view. This soil has very poorly preserved fossils, and cuts the underlying almost horizontally stratified beds. Remains of a soil base may be seen in scattered pieces. Above the soil are eolianite beds, dipping at 30° N., the transition beds showing very well. The soil merges above with the more recent soils.

The ages of the beds in this section are thought to be as follows. The lowest marine formation is considered of Belmont age. The conglomerate and overlying sands are without much doubt the Devonshire formation. The lower fossil soil is probably the Harrington,

FIGURE 8. A view of what is probably the Shore Hills-Harrington soil at the old fort site at Devonshire Bay. Note remnant of soil base under hammer, reduced by weathering of underlying horizontal formation. Also note thin transition beds and northward dipping eolianite. Fossils are rare and poorly preserved. Photo. by author. Locality 79.

FIGURE 9. The Shore Hills soil lying in patches on the Belmont marine formation at Grape Bay. Note the uneven surface of the Belmont where it has been stripped of the soil, and the solution holes in the Belmont. Hammer lies on soil. Photo. by author. Locality 130.

preserved by dunes soon after its formation, and hence kept in a fresh condition. The eolianite on the Harrington is of Pembroke age. The soil described in the old fort is not so easy to explain. On account of its extremely weathered condition and great thickness and its position on nearly horizontal beds, similar to the conditions at Wilson's Island, it might very well be of Shore Hills age. On the shore to the west of the lowest formations described above, are some holes in the Belmont which would appear to be of the "palmetto" type, and these in turn would indicate the former presence of the Shore Hills soil. It is most probable that the Shore Hills soil was here washed away before the deposition of the Devonshire formation, and that higher up the Harrington appears as probably a double soil with Shore Hills, and that the soil in the old fort is truly of Shore Hills age. Future study of this most important locality must be made before we can arrive at any definite conclusion. The location of the soil in the fort on beds very gently dipping towards the ocean, is so like the conditions at Wilson's Island, that it is logical to place this old soil provisionally in the Shore Hills-Harrington group of soils.

Hungry Bay (see plate 9). Excavations by the Road Department of the Bermuda Government have been going on here for the last few years to such an extent that to describe Hungry Bay as we saw it, would not help a visitor of today to any great extent. However this may be, an attempt will be made to describe this Hungry Bay locality as Clark and I first saw it in 1926.

The hard marine limestone is, as so often the case, the lowest member. Above this marine formation comes a soil about 18 inches thick, of a gray color and fine texture. The bottom of the soil has many marine forms and about midway these marine forms disappear and land forms take their place. This soil rises to the east at an angle of about 10° and as it rises the color changes to red and it becomes somewhat thinner. The soil rests on the marine formation at the lowest part of the exposure, a few feet higher up it rests on thin bedded sand rock not so completely consolidated, as it rises in the cliff, and cuts this sand rock. Eolianite dipping northeast rests on the fossil soil.

Of the formations described here, the marine formation at the base is without doubt the Belmont marine. Above this comes what must be the Devonshire marine formation, and the marine shells in the lower part of the soil are undoubtedly of this age. The Devonshire rises in the cliff under the soil. The fossil soil is the Harrington without much doubt. The eolianite on the soil is of Pembroke age.

The Shore Hills soil was not visible at the time we visited this locality, having been washed away when the waters of the Devonshire rose. This was also the case at Devonshire Bay.

Verrill described a section west of Hungry Bay, more accurately known as Grape Bay. I have not exactly located the section, but have seen one very similar at Grape Bay. The Spanish Rock, Devonshire Bay, Hungry Bay, and Grape Bay localities when studied comparatively, give a clear idea of the order of the formations along this south shore, and other places. Specially important is the fact that the Devonshire formation is entirely distinct from the Shore Hills, although belonging to the same long period of submergence, correlated in my table of formations with the Pleistocene, Yarmouth interglacial stage.

Grape Bay (Fig. 9). Here there is the usual resistant marine limestone at the base of the section. Lying on it is the Shore Hills soil in patches, the solution holes being filled with the soil. Above the soil comes a few inches of sand rock, which is undoubtedly of Devonshire age. Resting on this Devonshire is a red soil about a foot thick with fossil land gastropods, mostly *Poecilozonites bermudensis*. Resting on the soil are a few feet of eolianite of Pembroke age.

The importance of this Grape Bay locality cannot be over-estimated. Without it the problem of the Shore Hills and Harrington soils would not be clear. This is the only place I have found on the south shore where the Shore Hills is preserved to any extent. At Spanish Rock and at other places it may be found in "palmetto stumps," but here the soil itself, several inches thick, is seen lying on the surface of the Belmont and also in the solution holes. When the Devonshire submergence took place this Shore Hills soil escaped destruction on higher ground and merged with the Harrington, so that for the localities on the higher ground there was no interruption of the Shore Hills-Harrington episode, which was brought to a close with the advent of the Pembroke eolianite episode or stage. At Wilson's island the thick red soil called the Shore Hills, may be of Harrington age. The conditions here appear to be very similar to those at Hungry Bay. If such are the relations, the underlying thin-bedded rock at Wilson's Island must be of like age with the similar rock at Hungry Bay, which would make it Devonshire in age.

Elbow Beach (50a and 50b). The Elbow Beach locality displays at least four soils. The formations in order are as follows: a hard marine limestone at the bottom, undoubtedly of Belmont age, followed,

in ascending order, by a gray-brown soil 2 feet thick with a few fossil shell fragments; a layer of sand about 3 feet thick with *Poecilozonites bermudensis* var. *zonatus;* and a heavy red soil bearing fragments and fossil land snails, mostly *P. bermudensis* var. *zonatus.* This soil outcrops on the beach for over 200 feet and is very conspicuous. Northwards for about 200 feet and only slightly higher than the top of this fossil soil, is a wave-cut bench. At the inner margin of the bench, about 100 feet west of the path to the bath-houses, I saw the red loam of a soil recently excavated in the bench, and this was undoubtedly the same soil as that found on the beach. About 50 feet above this bench at the eastern end of the Elbow Beach Hotel, there was a very hard fossil soil about one foot thick, with a few fossils, and above this soil eolianite dipping east or northeast. Still higher up, at the top of the hill, there is a thin fossil soil, with many individuals of *P. bermudensis* var. *zonatus.*

In this section the lowest formation is Belmont marine limestone. Following this is the bleached Shore Hills-Harrington soil. Sands above the latter are of Harrington-Pembroke age. The thick, red soil is without doubt the St. George's soil. Lying on the St. George's soil is the Warwick eolianite. The soil at the east end of the hotel is the Signal Hill soil. Above the Signal Hill soil is the Somerset eolianite. At the top of the hill is the McGall's soil. The Elbow Beach section is important for comparison with other sections along the South Shore, and also with the sections about Hamilton. It is evident that wave action has cut back the section in more recent times, as is indicated by the bench, which is about eight to ten feet above sea-level.

Warwick-Paget line section (Fig. 10). This most important section in Bermuda gives an excellent exposure along the road that follows the boundary between the parishes of Paget and Warwick. On the south side of Hamilton Harbor, under the ferry waiting-room just west of the Inverurie Hotel, the Shore Hills soil, resting on the compact Belmont marine limestone, is well exposed. The soil is about eighteen inches thick and deep red. The overlying eolianite, the cross-bedding of which dips southward, is considered to be the Pembroke, the Harrington soil and the Devonshire limestone both being absent. On the road south from the Inverurie Hotel a red soil is exposed at the first house on the west side of the street, less than one hundred feet from the hotel. This is probably the Harrington soil, and the overlying eolianite Pembroke. About two hundred yards further south on the east side of the road this eolianite is in turn overlain by a fairly thick

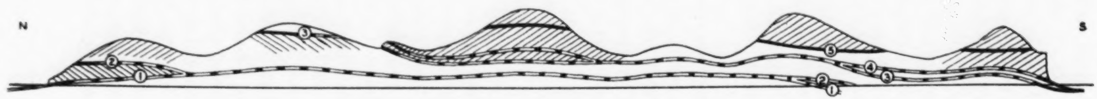

FIGURE 10. Partly hypothetical section across island on Paget-Warwick line.

1. Shore Hills soil.
2. Harrington soil.
3. St. George's soil.
4. Signal Hill soil.
5. McGall's soil.

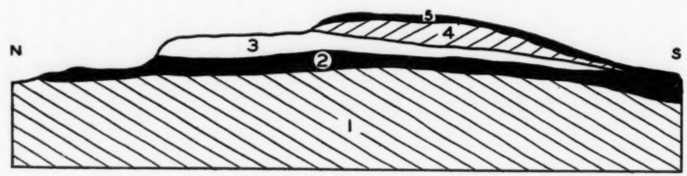

FIGURE 11. Section on Paget-Warwick road, about 200 yards south of Inverurie Hotel.

1. Pembroke eolianite.
2. St. George's soil.
3. Sands on soil.
4. Warwick eolianite.
5. Present soil.

Locality 125.

FIGURE 12. View of union of St. George's and Signal Hill soils at Simmons Beach. Note thickness of both soils, the transition beds above the Signal Hill soil, and the northward dipping Somerset eolianite. The lower parts of both soils, are weathered more deeply than the upper parts and probably represent a much longer time interval than the much thicker upper parts. Both soils have many fossils, mainly of the species *Poecilozonites bermudensis* var. *zonatus*. Photo. by author.

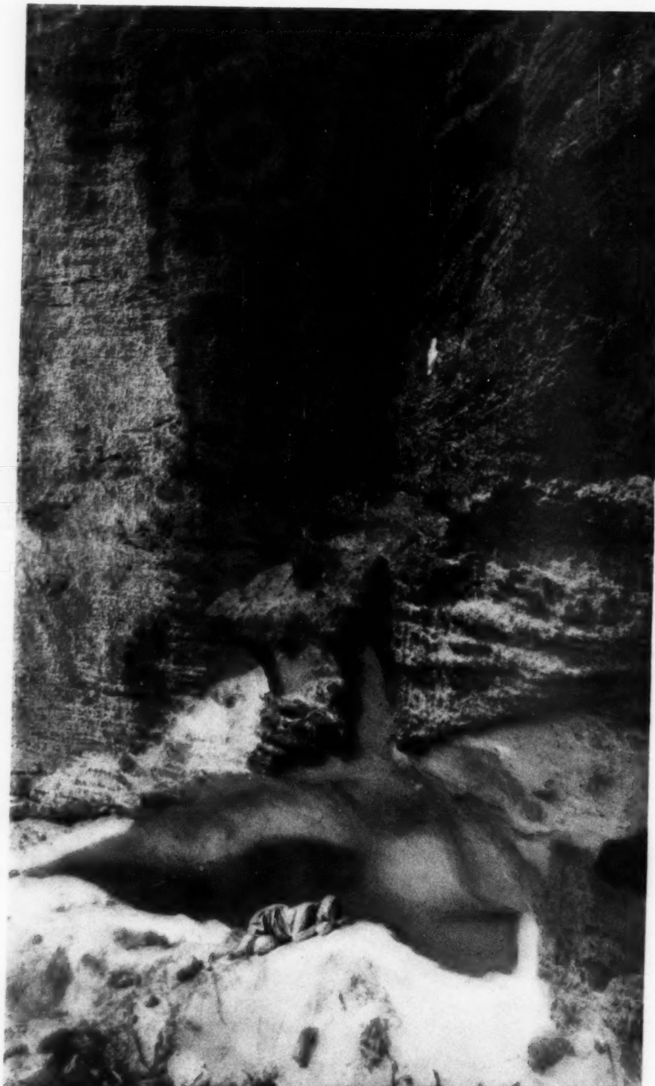

FIGURE 13. View of St. George's soil overlain by Warwick eolianite at Simmons Beach south shore. The thickness of the soil here is about 5 feet, and although it is largely a soil of accretion rather than weathering, weathering has progressed to a considerable extent, especially in the lower part. The beds of eolianite below are cut off. This soil, like all those at Simmons Beach, is full of the fossil *Poecilozonites bermudensis*, var. *zonatus*. The Warwick eolianite dips away from the observer at the common 30° angle of repose. Photo. by the author.

soil, which is correlated with the St. George's (Fig. 11). This soil dips gently to the north and has been cut off by erosion. A short distance to the south the north-south road is crossed by an east-west road, the "middle road." About one hundred feet east of the four-corners the St. George's soil, about three feet thick, is again exposed on the south side of the road; it dips southward. About fifty feet south of the four-corners the same soil is exposed a third time, although here it is not over nine inches thick. The underlying eolianite is considered to be the Pembroke; the superjacent eolianite, the Warwick. A still higher soil, the Signal Hill, is exposed at the crest of the next Hill, Mount Royal (see plate 6). It conforms to the surface of the hill rather closely, is about two feet thick, and shows considerable weathering. About three hundred yards still further to the south the Signal Hill soil, completely lithified, is once more exposed, at a point on the east side of the road. To the west of the road is a high hill of eolianite in which a quarry is located. This eolianite probably belongs to the Southampton formation. Further to the south there is a declivity in the road. In a pasture about fifty feet east of the declivity the Signal Hill soil is exposed as an indurated red rock. Crossing the South Shore Road and following a foot path past a small house on the east, a fossil soil underlying the recent soil is well exposed in a fresh cut. It may be the Signal Hill. The whole section may be seen in the cliff at Simmons Beach, where three soils are exposed (Figs. 12 and 13). The highest is correlated as McGall's, the lowest as St. George's. The soils are very thick and are underlain by soil bases. The lowest soil dips below sea level about three hundred yards west of the Paget-Warwick line, demonstrating that when it was formed sea-level was lower than now. Fossil land molluscs are extremely abundant and well preserved in all the soils in the cliff.

The North Shore. Along the North Shore road there are a number of outcrops of a thick red soil rising from sea-level and usually not far above it. Near Bailey's Bay on the south side of the road, the very characteristic old topography and deep weathering can be seen. In a 10-foot road cut about 200 feet west of Bailey's Bay, there is one of these thick soils. Here *Poecilozonites nelsoni* was found; hence it is safe to place this soil in the Harrington stage. At Cottage Hill on the side of the road is a thick soil, about fifty feet above sea-level. The fossil *P. nelsoni* was found here also, and this soil is without doubt Harrington in age. At the Shelly Bay race course in the rock under the grandstand is a thick soil about 25 feet above sea-level. Although *P. nelsoni*

was not found here, the general resemblance of this soil to those just mentioned, and its position would place it as Harrington. The eolianites overlying this Harrington horizon have not been searched for soils. Along the North Shore, from the Hotel Frascati to Spanish Point soils appear to be absent, but this may be because of the fact that this part of Bermuda has not been investigated thoroughly. It may be that all the eolianites and soils are represented here. Localities 83 and 85, north of Devonshire Marsh, prove that some, at least, of these later formations are present. On account of the absence of soils along this part of the North Shore, and the recent aspect of the hills, which still show dune contours, this part of Bermuda is considered to be of Wisconsin age, underlain by the older Pembroke—St. George's topography. Pembroke Marsh separates the older topography on the south from this younger topography on the north.

Hamilton Region. One of the most important regions in the study of the formations at Bermuda is that around the city of Hamilton, but it is frequently difficult to assign each soil to the proper stratigraphic horizon. On Reid Street, Hamilton (57) the Walsingham eolianite, very firm and compact, is exposed beneath a compound soil six feet thick (Fig. 14). The lower part of this soil is red and two feet thick; the upper part is pink, about four feet thick, and distinctly a soil of accretion, indicating a return to dune conditions. The lower part is of Shore Hills age, the upper of Harrington. At this locality the *Poecilizonites nelsoni* was found. A soil may be seen in the cliff near the Reid St.-E. Broadway junction. Continuing further east and bearing left up the hill called Middle Road, a pink soil may be seen on the left about half way up the grade. This is probably the Harrington. It is not over a foot thick. Above it is the Pembroke eolianite. At the top of the hill may be seen a thick red soil, two feet deep, which is provisionally assigned to the St. George's. Fragments of fossils have been found in these soils, but they have not been carefully studied. A. E. Verrill (*1907*, p. 74) cites Goldie (1867) as follows: "Prof. T. W. Goldie, in his printed lecture on the Geological Formation of Bermuda, reprinted in 1893, pp. 14, 15, mentioned a 'belt or layer' of 'red clay' soil, eight inches thick, underlying the eolian limestones near Hamilton. This layer was about 60 to 70 feet above sea-level and at about 130 feet below the surface of the hill. It was found in making a boring for a well at the military establishment on Prospect Hill. The layer of red clay was underlaid by strata of compact limestone. Perhaps this was part of the Walsingham formation."

This soil might be either the Shore Hills-Harrington or the St. George's soil.

The soil on Elliott Street is probably the most interesting in the city because of the deep pockets of weathering. On the south side of Elliott Street this soil is fully four feet thick and of a deep-red or chocolate-brown color. One of the pockets is four feet deeper, making the total thickness of the soil at this point eight feet (see plate 2). Obviously a long period of weathering is involved. Under this soil many fossils have been found, the most common species of which is *Poecilozonites bermudensis*. On the north side of the street the same

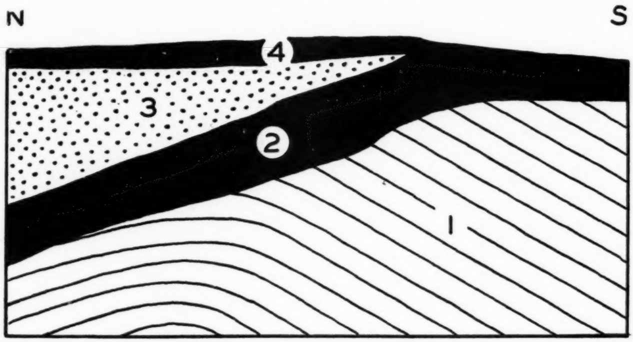

FIGURE 14. Reid Street section.

1. Walsingham eolianite.
2. Shore Hills-Harrington soil.
3. Sands belonging to late Harrington time.
4. Present soil merged with Harrington.

Note erosion of Walsingham under soil. Locality 57.

soil can be seen near the top of the cut, but it is not over a foot thick. Evidently the soil on the south side accumulated in a hollow. The same soil may be followed northward on the west side of Cedar Avenue. It contains many specimens of *P. bermudensis*, but *P. nelsoni* has not been observed. This soil is placed provisionally in the St. George's.

Further east in the new cut on Elliott Street there is a splendid exposure on both sides of the road. The soil may be either the St.

FIGURE 15. Section of a dune of eolianite north of Pembroke marsh, near Hamilton. The wind direction was north, or from left to right in the view. The middle and back of the dune are shown, the middle beds about horizontal and the back beds dipping at an angle of about 30°, the angle of repose for this material. Photo. by author.

George's or Signal Hill (see plate 4). On Pitts Bay road near the entrance to the Princess Hotel there is a thick soil only a few feet above sea-level exposed in the cliff under the road (55). This soil is about eighteen inches thick, of a red color, and contains many small species of fossil snails which are commonly found in the Harrington-Shore Hills soil (to which it is assigned); but none of *P. nelsoni.*

About one hundred yards north of the entrance to the Princess Hotel a street connecting Pitts Bay road with Serpentine road leads to a very good soil exposure about half-way between the two roads (59). The soil is exposed on the west side of the street. On account of its fossil content, its thickness, and the large amount of erosion that has taken place since its formation, it is considered to be St. George's. It is without much doubt the same soil as that found on Elliott Street (98).

On the southwest border of Pembroke Marsh, along the southwest side of Serpentine road there is a soil exposure (31) four feet thick about ten feet above sea-level. Because of its great thickness and position it is assigned to the Shore Hills-Harrington horizon. The same soil may be seen again at locality 30 further west. At locality 27, just before crossing the small bridge to the Grasmere Hotel, there are two soils on the south side of the road, a lower one about two feet thick devoid of fossils and an upper thicker soil. A soil-base divides the two soils. The age is without much doubt Shore Hills-Harrington, and the upper soil may represent all post-Harrington time.

There are a number of other fossil soils in the region which should be noted. The two soils back of the Opera House on Victoria Street deserve mention (see plate 5). The section here in downward succession is: (1) recent soil; (2) white eolianite; (3) upper soil of light pink color between three and four feet thick, dipping gently northward, and with an irregular lower surface due to solution cavities—a soil base present; (4) about three feet of white eolianite; (5) a red soil one foot thick dipping gently northward; even soil base without solution cavities; consolidated sand-rock above and below the soil. The age of this group is difficult to determine without further study of the Hamilton region. The lower soil is probably Shore Hills, the upper Harrington or St. George's. There is a thick soil about 300 feet east of the Opera House, but the age is unknown.

In a general way the parish of Pembroke may be divided into two parts, an area south of Pembroke Marsh, which is underlain mainly by the Pembroke and older eolianites, and an area of higher land to the

north, which is underlain by the younger eolianites. These relations are discussed more fully in the section on physiography.

Walsingham Cave District. The Walsingham Cave District, located between Castle Harbor and Harrington Sound, is specially important because of the excellent development of the Walsingham eolianite. This eolianite, which forms the base of the stratigraphic column in Bermuda, reaches higher elevations here than elsewhere. It is compact, well jointed, and deeply pitted. Since this formation is found at elevations as much as one hundred feet above sea-level and inasmuch as the Belmont and Devonshire marine limestones are not found at elevations greater than twenty-five feet, we may conclude that this particular part of Bermuda has stood above water ever since Walsingham time.

The foreset beds of these cross-bedded eolian limestones dip steeply to the east and northeast, demonstrating that the dunes migrated from the west or southwest, that is, out of what is now Harrington Sound. This body of water may fill a limestone sink or it may be an inter-dune depression. The paucity of younger eolianites in the Walsingham Cave District confirms the observation already made in Pembroke parish, that the younger dunes are confined to the coast.

At Crystal Cave the relations of the rocks can be seen very well. Just inside the iron gate of the cave, on the north wall, a soil with large *Poecilozonites nelsoni* may be seen. This is considered to be the Shore Hills soil. The underlying eolianite is Walsingham, the upper eolianite Pembroke. In the government quarry near Paynter's Vale the Walsingham formation is well exposed. There are many fossils in the overlying soil, among them *P. nelsoni.* Around the large sink hole near the center of the quarry are many kinds of fossils, including crabs, bird bones, and snails. A complete study of this locality would undoubtedly yield a great deal of information.

The caves of this area are described in a later page dealing with the physiography of Bermuda.

The Islands near Hamilton. The islands near Hamilton and as far away as Little Sound and Southampton furnish a problem so closely connected with the fossil soils found on them that a brief word must be said about their origin and history.

There are two groups, an outer group and an inner group. Hawkins Island, Long Island, Agar's Island and a number of smaller islands form a crescent, and may be considered the outer islands. I have been unable to find evidence of fossil soils on any of these. The inner

group comprises many, but it is unnecessary to name them all. The more important ones are, Hinson, Marshall, Darrell, Burt, Grace, Wilson's, Morgan's and Tucker's. The Belmont marine is surely found at Marshall Island and at locality 37 north of the Belmont Hotel. As the soil on Darrell Island was seen from a boat only, on the last visit to Bermuda, I cannot say whether the Belmont occurs there. The same is true of locality 101 near Burgess Point. The Devonshire marine formation is found on Agar's Island, Marshall Island and on Wilson's Island.

These inner islands are all the product of erosion. None of the original dune forms are preserved, while in western Pembroke dune-shapes can be seen, the result of Wisconsin dune-building, at least on the tops of the hills. The Devonshire formation on Agar's Island is not even well consolidated, while the Belmont formation noted above is very resistant and has a decidedly old appearance. It does not seem possible that these can be the same marine formation. In any event, erosion is responsible for the shapes of the inner islands and erosion went much deeper than the present sea-level, since several of the fossil soils dip well below sea-level, as at Hinson Island and Marshall Island. It is evident that the soils were to a large extent formed during a time when the water-level was lower than it is today, and as the water-level was considerably higher during the Shore Hills stage than now, all that can be said is that the Shore Hills soil in these islands was formed when the water-level had subsided considerably from its highest point. Of course this was true of the Shore Hills locality and was probably true of all the places where the Belmont and Shore Hills formations are seen together. A cave was found by divers in the ship channel in Hamilton Harbor 30 feet below the present sea-level, with stalactites and red soil. Hence it was during a time of low water that this region was eroded. What prevented dune formation here at that time? Cressy has shown that dunes always follow a retreating body of water, as in the case of the dunes at the southern end of Lake Michigan. He found that the recent dunes there were formerly near the lake at a higher stage and that the old dunes were far away, and well set. The Hamilton region during this time of low water was protected from dune activity, as was the case about the Walsingham cave district. Dunes did not enter there. The erosion of these islands continued through the Pembroke, the St. George's, and all later stages of the Pleistocene, and the result is as we see it today. I have supposed that this whole island region was continuous

land during the time of the formation of the Shore Hills soil, and that valleys were eroded in it fully as much during a stage or stages of low water, as of high water, and that when the sea-level rose again these valleys became filled by marine waters as we see them today. Actual subsidence of this inner group of islands is the other alternative. Harrington Sound might be explained in the same manner. It is not impossible that certain areas had subsided, but if this actually happened, the main hypothesis of this paper would not be essentially affected.

Several localities among the inner islands are very important: Hinson Island, Marshall Island, Wilson's Island, and Tucker's Island, and along the shore of the main island, likewise the Salt Kettle exposure, the Inverurie and the Belmont shore exposures. These will be taken up in order.

Hinson Island (Fig. 16), the most easterly of the few displaying soils, was visited in 1926 by Clark and the writer. At the prominent soil exposure on the west side of the island (105), at the water's edge, Clark found a *P. nelsoni* in sands just above the red soil,

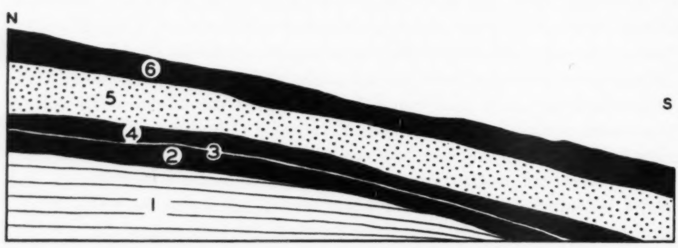

FIGURE 16. Hinson Island section.

1. Walsingham eolianite.
2. Shore Hills soil.
3. Soil base.
4. Shore hills or Harrington soil?
5. Sands with fossils.
6. Harrington soil?
Locality 105.

and I found a specimen of the same species, poorly preserved, in the deep-red soil itself. Eolianite underlies the deep-red soil. The soil is divided by a soil base and thus is really a double soil. This fact may not be clear near the water's edge, but on the side of the hill, about 100 feet north, this soil base is well seen between the two soils. Complete

consolidation makes both of them very hard above the sea-level outcrop. Overlying are sands about 3 feet thick with fossils, and above the sands, another soil with fossils. All the soils and intercalated sands dip about 10° to the southwest. Following the lower soils northward they are seen to reach the uppermost part of the island and encircle it, forming a kind of crown about the top.

I believe that the underlying eolianite is of Walsingham age, that the lowest soils are of Shore Hills age and that the sands and overlying soil are of Harrington age. The Pembroke formation is missing here, although there may be a slight remnant of it near the top of the island. This locality closely resembles that at Wilson's Island. There is no record of *P. nelsoni* having been found among these islands until Clark and I found it there in 1926. Like the other inner islands, Hinson Island is a remnant of the old land of Bermuda and a most important place for study.

Marshall Island (104) is the next island northwest of Hinson. At its eastern end, near Timlin's Narrows, a deep red soil can be seen close to the water's edge. It is almost horizontal but dips slightly southward. Here the order of the formation is as follows: a very hard limestone extending below sea-level and containing marine fossils; above it loosely consolidated sand rock about 3 feet thick, possibly of marine origin, and dipping gently east; on this sand rock a deep red soil about 2 feet thick with *Poecilozonites nelsoni* to the southwest, eolianite lying on the soil. Mather found fossils in the marine limestone and I found several specimens of *P. nelsoni* in the soil. The soil appears to be single. It dips gently below sea-level.

The marine limestone is without doubt of Belmont age. The sands above are probably of Devonshire age. The Shore Hills soil does not appear on the Belmont, as it does in most places, and was probably eroded. The soil is without much doubt of Harrington age.

The soil at Inverurie, (102), has already been described under the section called the Paget-Warwick line. The Salt Kettle locality 45, and the Belmont locality 37, also face the inner islands on the south, and present a common problem.

The Salt Kettle (45). About 200 feet south of the ferry station on the east, and forming part of the wall of a very small house, is a hard pink soil about one foot thick, dipping north. The eolianite under this soil dips south, a relation like that represented at the Inverurie locality. Hence the Salt Kettle soil is probably of Harrington age. About 200 feet south of this soil the eolianite also dips south. It is probably the same eolianite found under the soil, at the house.

The Belmont soil, (locality 37), can be found at an opening in the wall north of the Belmont Hotel and close to sea-level. The soil here is underlain by the Belmont formation, in which I found several marine fossils. This is a very compact rock. The soil itself—the Shore Hills soil—is about three feet thick and dark red. On account of its thorough weathering, fossils are scarce. At the bottom of the soil is a breccia resembling that at Stokes Point.

Wilson's Island, (locality 129) (Fig. 17). The next section in order would be that just east of Burgess Point in the cliff, and that on Darrell Island. Unfortunately there was not time to visit these exposures, which were seen only from a motor boat.

The good section at the small Wilson's Island, will be described next. The island lies about 100 yards off-shore at the base of Gibbs Hill. The lowest formation here is a thinly stratified marine or eolian sand-rock dipping very gently northwards. If it is marine, as is most probable, it is of Devonshire age; if eolianite, it is of Walsingham age.

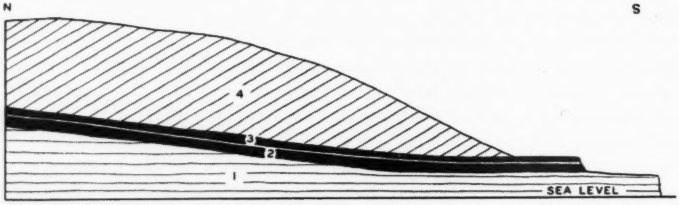

FIGURE 17. Wilson's Island section.

1. Devonshire marine limestone?
2. Harrington soil?
3. Harrington soil?
4. Pembroke eolianite.

Locality 129

On a shelf cut into this formation, sloping gently northward and upward, is a deep-red soil about 2 feet thick. The soil cuts the underlying formation. A poorly preserved specimen of *P. nelsoni* was found here. Above the deep-red soil come sands, as at Hinson Island, then a light colored soil with many fossils, mostly *P. bermudensis*. Above this soil comes northward dipping eolianite at the foreset angle of 30°. The lowest formation here, as noted above is of Devonshire or Walsingham age. The deep-red soil is undoubtedly of Harrington age, and the sands and soil above them of Harrington age. The eolianite resting

on the Harrington is of Pembroke age. It can be seen readily that the shape of the island is due entirely to erosion.

Only those islands of the inner group have been mentioned where fossil soils have been found.

Tucker's Island (locality 127), the most westerly of the inner group, has long been noted for its cave. Before the other caves were discovered many people visited Tucker's cave, and a reminder of their visits has been left in the blackened roof and stalactites caused by the smoke from torches used for illumination. It is impossible to see this cave without a boat. Verrill speaks of finding some *P. nelsoni* fossils just above the entrance to the cave. This must indicate the former presence of the Shore Hills soil and remnants of this soil can still be seen. The rock in which the cave was formed is probably of Belmont age, but this point awaits further investigation. The top of this formation is about 15 feet above sea-level. No eolianite was seen and it is evident that any eolianite that may have been formed here was eroded, together with most of the soil.

FOSSIL SOILS.

Character and Origin.

R. J. Nelson (*1840*) noted that the soils now forming on Bermuda are gray on hillsides, but red in valleys and hollows. The light-gray or pink soils found on the slopes usually have a large percentage of lime carbonate, whereas the deep-red or chocolate-colored soils found in the depressions are composed largely of silica, alumina, and iron. Similar relations are found in the fossil soils. The St. George's soil displays these features in the exposure on Ferry Road, St. George's, just east of the railroad cut, in the cliff on the north side of the road. Where the soil is at its lowest elevation it is deep-red and about eighteen inches thick. It rises both to the east and the west, becomes thinner and lighter-colored, eventually attaining a pink tinge. In several places it has been eroded away. The pink portion contains many fossil snails, which are completely lacking in the deep-red part. It is evident that as fast as the oxidized material formed it was washed into the hollows by the run-off.

Three processes have been active in the production of the soils of Bermuda. Much of the material is obviously residual, the insoluble residue of large amounts of eolianite. Soils of this type are well oxidized and either deep-red or chocolate-brown. A second process is

by accretion from above. Fine calcareous sediment blown around by the wind has frequently contributed a large quantity of material to the soils. Such soils are very light-colored, either cream, pink, or gray. Thirdly, the material formed by either of the two processes just outlined may be concentrated in hollows by rain-wash. It is frequently difficult to evaluate these three processes. In general, however, a soil of accretion will be much lighter in color than a residual soil. Moreover, it would be difficult for a strictly residual soil to form on a steep hill-slope. Rain-wash would convey the minute particles of decomposition to lower levels about as fast as they formed, leaving on the hill-sides a relatively thin soil composed of fresh material. The fossil soils of Bermuda show such relations. Wherever they rest on a relatively steep slope they are pink or gray rather than red, indicating a greater percentage of unoxidized material. In the hollows the fossil soils are red or chocolate-brown. The color of a soil at any particular spot is therefore a result of a number of variables, among which should be mentioned position, method of formation, and length of time involved in accumulating the soil.

A. E. Verrill (*1907*, p. 57) made a careful estimate of the time necessary to form a strictly residual soil. From a study of the rate of disintegration of the old stone forts on Castle Island and other islands, some of which were probably built before 1620, he concluded that it "would require 120,000 years for the destruction of the two hundred feet of hard limestone necessary to form one foot of soil." He states that other evidence checked with this conclusion. The petrologic study in this paper also shows that Verrill's estimate of the amount of eolianite that must be destroyed to form a foot of soil is of the right order of magnitude. Our work suggests that one hundred feet of eolianite would give one foot of soil. If so, a foot of soil might accumulate in 60,000 years. Post-glacial soils in limestone regions of the United States are about six inches thick. If we take post-glacial time as about 25,000 years,[1] a foot of soil might accumulate in 50,000 years.

A soil developed on low flat land would probably form at some such rate, that is, one foot in from 50,000 years to 120,000 years. But a soil concentrating in a hollow would increase much more rapidly, due to the large amount of material washed in from the surrounding slopes.

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[1] G. F. Kay, The relative ages of the Iowan and Wisconsin drift sheets, Am. Jour. Sci., vol. 21, pp. 158–172, 1931.

For example, it has already been mentioned that the St. George's soil on Ferry Road is eighteen inches thick in the bottom of the depression. But much of this has been washed in from the nearby slopes. Finally, the soils of accretion, would accumulate much more rapidly, perhaps within a few thousand years.

The estimates may be applied with confidence, however, to soils formed on a low land-surface which had been reduced by long erosion. The Shore Hills soil on Marshall's Island was formed under such conditions and is about two feet thick. It would take from 100,000 to 240,000 years for such a soil to accumulate. At the Shore Hills quarry the deep residual soil, representing Shore Hills and Harrington time combined, is about four feet thick and in certain pockets twelve feet thick. The smaller figure suggests that it took from 200,000 to 500,000 years for this soil to accumulate. Since the Harrington is usually a soil of accretion, it probably accumulated in a relatively short time and most of the figures given above should be assigned to Shore Hills time. A fair average for the length of Shore Hills time would be perhaps 200,000 years ± 50,000.

On flat surfaces the St. George's soil is about two feet thick, indicating an interval of 100,000 to 240,000 years. It never attains the great thicknesses noted for the Shore Hills-Harrington soil. A fair average for St. George's time would be about 150,000 years ± 50,000. Unfortunately the upper two soils, the McGall's and the Signal Hill, are never found in suitable topographic positions for making accurate estimates of the length of time involved in their accumulation. Moreover, they are largely soils of accretion. They undoubtedly accumulated much more rapidly than the residual soils, perhaps within a few thousand years. The modern soil has probably accumulated within post-Wisconsin time, that is, within 25,000 years, for its thickness, six inches, is of the right order of magnitude.

All these estimates are admittedly crude. The errors may be considerable, but the figures nevertheless are probably of the right order of magnitude. They indicate that several hundred thousand years were necessary for the production of the fossil soils of Bermuda. In addition, periods of unknown length were involved in the accumulation of the eolianite. Moreover, the figures clearly show that the soil-making ages were of vastly different lengths. Shore Hills-Harrington time lasted 200,000 years, St. George's time 120,000 years, Signal Hill and McGall's time a few thousand or tens of thousands of years each, and post-eolianite time 25,000 years.

Soil Bases.

Between each soil and the underlying eolianite there is frequently a thin layer of cream-colored, compact, finely crystalline limestone from one-half inch to two inches thick. Similar material coats the surface of many of the hills in Bermuda at the present time, due to the removal of the soil because of deforestation. At several localities the fossil soil is not only underlain by a soil base, but a similar layer divides the soil into an upper and a lower part. I interpret such compound soils as indicating two distinct soil-forming episodes separated by a long interval of time. At Pink Beach, for example, there are two soils separated by five feet of eolianite; the lower soil is four feet thick, the upper two feet. The upper soil, however, is actually compound, for in addition to the soil-base beneath it there is a much broken soil-base dividing the soil into two parts.

PALEONTOLOGY.

Introduction.

A detailed paleontological study of the fossil soils was made in the hope that the relative ages of the formations might be determined, and also, that index fossils might be established for distinguishing the various soils. Unfortunately the results are largely negative, or at the best inconclusive, at the present time. None of the snails, foraminifera, or algae is of any help in determining the age of the formations, other than that they are either Tertiary or Quaternary. The snails, however, may prove useful as index fossils. *Poecilozonites nelsoni* is confined to the Harrington soil and older formations. Many other species of snails are now extinct, but sufficient data were not obtained to determine the exact horizon to which each is limited. What relevant suggestions can now be made are indicated in Table III. This may be a profitable method of attack in the future.

TABLE II. Paleontology of the Fossil Soils.

Identifications by T. H. Clark.

Locality Nos.		
1.	Poecilozonites bermudensis var. zonatus	St. George's soil Ferry Road.
	" reinianus	St. George's.
	" circumfirmatus	
	Succinea somersensis	
5.	Poecilozonites bermudensis var. zonatus	Signal Hill soil.
	" circumfirmatus	
	Succinea somersensis	

Locality Nos.		
6.	Poecilozonites bermudensis var. zonatus " circumfirmatus	Soil in cliff north of Signal Hill, by shore. McGall's soil?
7.	Peocilozonites circumfirmatus	About 1500 ft. west of Tobacco Bay.
10.	Poecilozonites reinianus " circumfirmatus	Mullet Bay. At sharp curve in road south of Davis' Hole. Thick soil 18″ with marine fossils at bottom and land snails above. About 6′ above sea-level. Harrington soil.
13.	Poecilozonites nelsoni " " var. callosus " circumfirmatus " bermudensis var. zonatus " reinianus Strobilops hubbardi Succinea somersensis	Spanish rock. Soil 12″–18″ light colored. Many fossils, but soil discontinuous laterally. Situated in sea-cave about 15 feet above sea-level. Harrington soil.
15.	Poecilozonites bermudensis var. zonatus " reinianus " circumfirmatus Vertigo numellata Carychium bermudense Succinea somersensis	Albuoy Point. This is probably the Harrington soil.
16.	Poecilozonites bermudensis " circumfirmatus " cupula " dalli Succinea somersensis	Albuoy Point. Near 15 and probably the same soil.
17.	Poecilozonites cupula " dalli Succinea dalli	Albuoy Point. In the same cut, and probably the same soil (17).
18.	Poecilozonites bermudensis var. zonatus " circumfirmatus Succinea somersensis	Shelly Bay race course. Harrington soil.
19.	Poecilozonites nelsoni " bermudensis var. zonatus " reinianus " circumfirmatus	Cottage Hill. Outcrops on side of road cut. About 50′ above sea-level. Harrington soil.
20.	Poecilozonites nelsoni " bermudensis var. zonatus " reinianus " circumfirmatus	Bailey's Bay. In 10′ road cut just west of Bailey's Bay. Dips S. W. 30. Harrington soil.

Locality Nos.		
21.	Poecilozonites bermudensis " circumfirmatus	Surf Beach. Fossils found on sea-cut shelf about 10′ above sea-level. Sea caves along shore at same altitude. Deep red soil. Harrington.
22.	Poecilozonites bermudensis " circumfirmatus Vertigo numellata Carychium bermudense Succinia somersensis	Surf Beach. Half way up concrete steps. St. George's soil.
23.	Poecilozonites bermudensis var. zonatus	Town Cut. Soil on each side of cut, each about 1′ thick and dipping gently northeast and west. Higher on south side of cut. St. George's or Signal Hill?
24.	Poecilozonites reinianus	Stokes Point. Soil lying on Shore Hills marine. In lower part many marine fossils and in upper part many land forms but mostly one species. Shore Hills soil.
33.	Poecilozonites bermudensis " reinianus " circumfirmatus Thysanophora hypolepta Carychium bermudense Succinea somersensis " barbadensis	Serpentine Road, Hamilton (59). Shore Hills-Harrington soil.
42.	Poecilozonites bermudensis " circumfirmatus	Soil on road south of Jews Bay. Signal Hill or McGall's soil?
43.	Poecilozonites bermudensis var. zonatus Euconulus turbinatus Succinea bermudensis	About ¼ mile farther west than locality 42 and probably the same soil.
46.	Poecilozonites bermudensis var. zonatus " circumfirmatus	At head of Mangrove Bay near the Somerset-Watford bridge. Marine forms in lower part and land forms in upper part. About 6′ above sea-level. Harrington?
55.	Poecilozonites bermudensis var. zonatus " circumfirmatus	Princess Hotel Harrington soil.

Map Nos.		
57.	Poecilozonites bermudensis var. zonatus... " circumfirmatus	Reid Street soil. Very red and thick at bottom. Almost no fossils found. Shore Hills-Harrington.
66.	Poecilozonites bermudensis var. zonatus... P. circumfirmatus Succinea bermudensis Euconulus turbinatus Vertigo numellata Carychium bermudense Bifidaria jamaicensis Thysanophora hypolepta Zonitoides bristoli	Lowest soil exposed along the cliffs at McGall's Bay locality. Pale color, horizontal, and continuous with the soil of Loc. 69 and 78. Many fossils, especially small species. Harrington soil.
67.	Poecilozonites bermudensis var. zonatus... P. circumfirmatus P. blandi Succinea bermudensis Carychium bermudensis Zonitoides bristoli Bifidaria servilis	Fossils found in sand lying on soil 66, and part of it.
68.	Vertigo numellata Carychium bermudensis Bifidaria jamaicensis Thysanophora hypolepta Zonitoides bristoli	A red soil above 67. This soil is continuous to the east with 77, and to the west with 70 and 72. Fossils all small species. St. George's soil.
69.	Poecilozonites bermudensis var. zonatus... P. circumfirmatus P. vanattai angulifera Succinea bermudensis Euconulus turbinatus Vertigo numellata Carychium bermudensis Bifidaria jamaicensis Thysanophora hypolepta Zonitoides bristoli	Lowest soil seen in the cliff at western end of McGall's Bay locality. Stratigraphically continuous with 66. Many fossils. Harrington soil.
70.	Poecilozonites bermudensis var. zonatus... P. circumfirmatus P. vanattai	A red soil lying above 69. In places cavities filled with fossils and boulders. Filling may be of recent date. Fossils scarce. St. George's soil.
72.	Poecilozonites bermudensis var. zonatus... P. circumfirmatus P. vanattai	A red soil lying not far below 75. It is the equivalent of the soil of 70 and also 68 and 77. St. George's.

Map Nos.		
74.	Poecilozonites bermudensis var. zonatus P. circumfirmatus P. gulicki P. reinianus Succinea bermudensis Euconulus turbinatus Bifidaria jamaicensis	Soil continuous with 73. Fossils of 73 and 74 recorded together. McGall's soil.
75.	Poecilozonites bermudensis var. zonatus P. circumfirmatus P. reinianus	A pink soil of great horizontal regularity, continuous with soil 71. Along the cliffs to the east this soil is less regular. Few fossils. Signal Hill soil.
76.	Poecilozonites bermudensis var. zonatus	Fossils from sands lying in the lowest soil, about 1000′ east of loc. 66. Harrington sands. Transition.
77.	Poecilozonatus bermudensis var. zonatus P. circumfirmatus	This is a very strong red soil with a pink one above. No sands lie between them. These two soils are indisputably the red and pink soils of localities 70 and 71. The fossils were found only in the red lower soil. St. George's and Signal Hill soils.
78.	Poecilizonites bermudensis var. zonatus P. circumfirmatus Succinea bermudensis	This soil lies on a bench about 6′ A. T., in precisely the same position as does the same soil at loc. 66 and 69. Fossils are rare. Harrington soil.
79.	Poecilozonites bermudensis var. zonatus P. circumfirmatus P. blandi Vertigo numellata Carychium bermudense Thysanophora hypolepta	This is a very strong red soil, one to two feet thick, on the path through the old fortifications at Devonshire Bay. Downwards it grades into disrupted eolianite. It is covered by about 4″ of transition sands. This zone carries many *P. zonatus.* It dips under the hill in a southwesterly direction, and is probably continuous with the soil of loc. 81 and 82. This

Map Nos.		
		would make it of Harrington age. It is possible, however, that it overlies that soil, in which case it would be St. George's in age.
80.	Poecilozonites bermudensis var. zonatus P. circumfirmatus P. blandi Vertigo numellata Carychium bermudensis Thysanophora hypolepta Zonitoides bristoli	A pale soil under the cliff at Devonshire Bay. Below it is a coarse sand rock of the Devonshire-Harrington soil.
81.	Poecilozonites bermudensis var. zonatus Succinea bermudensis	A red soil on both sides of a small hill east of Cox's Bay. Age not determined.
83.	Poecilozonites bermudensis var. zonatus P. circumfirmatus var. discrepans P. blandi	This is a light colored but thick soil in a large quarry in the northern end of Devonshire marshes. It contains many P. zonatus fossils mostly with traces of their original coloring. It dips steeply to the south. Age not certain, but on account of the great number of P. zonatus fossils it should be one of the later soils.
84.	Poecilozonites bermudensis var. zonatus P. circumfirmatus P. blandi Vertigo numellata Carychium bermudensis Thysanophora hypolepta Zonitoides bristoli	Transition sands immediately above 83. Above this sand was found by Clark, a hermit crab shell, Livonia pica, at least 100 feet A. T. These sands belong in age to the soil underneath.
86.	Poecilozonites bermudensis var. P. circumfirmatus var. discrepans P. reinianus P. blandi	Soil in pits near road level of the big quarry of loc. 83, and possibly the same soil as 83.

Fossil Snails.

After accompanying the writer to Bermuda twice, Clark studied the collections and prepared the locality list (Table II). Twenty-six species of snails have been found. The most abundant and

interesting genus is Poecilozonites, which is indigenous to Bermuda. Twelve species of this genus, some of which are extinct, are found in the fossil soils of Bermuda. *Thysanophora hypolepta* is also confined to Bermuda. *Strobilops hubbardi,* although extinct in Bermuda, is still living in the Gulf states and Jamaica. *Bifidaria jamaicensis* lives not only in Bermuda but also in the Greater Antilles; *B. servilis* lives in Cuba and other West Indian islands.

TABLE III. STRATIGRAPHIC PALEONTOLOGY.[1]

Species	S.H.	H.	St.G.	Sig.	M.	Present
Poecilozonites bermudensis var. zonatus Verrill		x	x	x	x	?
P. reinianus (Pfeiffer) Pilsbry	x	x	x	x	x	Living
P. circumfirmatus (Redfield) Pilsbry		x	x	x	x	Living, very common
P. nelsoni (Bland) Pilsbry		x				Extinct
P. nelsoni var. callosus Gulick		x				Extinct
P. cupula Gulick		x				Extinct
P. dalli Gulick		x				Extinct?
P. vanattai angulifera Pilsbry		x				Living
P. vanattai Pilsbry			x			Living
P. gulicki Pilsbry					x	Extinct
P. blandi Pilsbry		x	?			?
P. circumfirmatus var. discrepans (Pfeiffer) Pilsbry						Living, not Common
P. bermudensis (Pfeiffer) Pilsbry		x	x	?	?	Living
Succinea somersensis Verrill		x	x	x		Living
S. bermudensis Pfeiffer		x		?	x	Extinct?
S. barbadensis Guilding						Living
Strobilops hubbardi (Brown)		x				Not living in Bermuda
Vertigo numellata Gulick		x	x			Extinct?
Carychium bermudense Gulick		x	x			Extinct?
Thysanophora hypolepta (Shuttl.) Pilsbry		x	x			Living
Euconulus turbinatus Gulick		x		?	x	Extinct?
Bifidaria jamaicensis C.B.Ad.		x	x		x	Living
B. servilis, Guilding		x				Living
Zonitoides bristoli Gulick		x	x			Extinct

[1] x indicates form present. ? indicates soil not definitely identified, S.H. Shore Hills, H. Harrington, St.G. St. George's, Sig. Signal Hill, M. McGall's.

Table III shows in what soils each species has been found and also indicates whether they are living or extinct. The soils are arranged chronologically, the oldest at the left. Unfortunately the collections were largely confined to the Harrington soil. In future work, more extensive collections should be made from all the soils and a set of index fossils established from known localities. At the present time all that we can say with confidence is that *P. nelsoni* is confined to the Harrington and older formations and that *P. bermudensis* var. *zonatus* is very abundant locally in the St. George's, Signal Hill, and McGall's soils.

Foraminifera.

The writer is greatly indebted to Professor Joseph A. Cushman and Mr. Lothrop Bartlett for studying the foraminifera. The former has studied the foraminifera from the fossil soils. Most specimens were rounded by wind action and are somewhat decomposed.

Cushman states that these are living forms which live in water not over twenty fathoms deep and under climatic conditions similar to those which now prevail on the islands. Since these genera have varied but little since Pliocene time, they can not be used as horizon-markers. Evidently the foraminifera have been blown inland and incorporated in the soils.

Mr. Bartlett, when a student at Professor Cushman's laboratory, determined the foraminifera of the sand-rock. It will be noted from Table IV that there are very few species in the soils themselves and the immediately underlying coarse-grained sand-rock, but that in the much finer-grained, overlying eolianite many species are present. The greatest number of species found in any soil was eight, and usually there were fewer than four. The same general features exist in the coarse sand-rock. But in the fine-grained sand-rock thirty-four species were found in one specimen. The larger number of species found in the fine-grained eolianite would suggest the lowering of sea-level and exposure of the fine-grained mud to wind action. This might well indicate renewal of glaciation on the continents. The species are listed in Table IV.

TABLE IV. Foraminifera.

Foraminifera from fossil soils of Bermuda. (Determined by Joseph A. Cushman).

1. Alveolina pulchella.
2. Amphistegina lessoni.

3. Carpentaria.
4. Gypsina.
5. Massilina.
6. Orbiculina adunca.
7. Orbiculina pulchella.
8. Orbitolites.
9. Quinqueloculina dilatata.
10. Texularia agglutinans.
11. Triloculina oblonga.

Foraminifera from coarse sand below soil like beach sand. Locality 46. (Determined by Lothrop Bartlett).

1. Asterigerina carinata d'Orbigny.
2. Archais aduncus (Fichtel and Moll).
3. Quinqueloculina sp.
4. Amphistegina lessonii d'Orbigny.

Foraminifera from fine-grained eolianite above soil, like material from lagoon bottom. Locality 86. (Determined by Lothrop Bartlett).

1. Textularia agglutinana d'Orbigny.
2. Quinquelo culina agglutinana d'Orbigny.
3. " auberiana.
4. " circularis.
5. " parkeri (H. B. Brady) var. occidentalis Cushman.
6. " polygona d'Orbigny.
7. " sp.
8. " sp.
9. Hauerina bradyi Cushman.
10. Triloculina carinata d'Orbigny.
11. " fichteliana d'Orbigny.
12. " linneiana d'Orbigny.
13. " oblonga ? (Montagu).
14. " planciana d'Orbigny.
15. " sp.
16. Biloculina denticulata (H. B. Brady).
17. " subsphaerica d'Orbigny.
18. Vertebralina cassis d'Orbigny.
19. Elphidium lanieri (d'Orbigny).
20. Peneroplis pertusus (Forskal).
21. " planatus (Fichtel and Moll.)
22. " proteus d'Orbigny.
23. Archais aduncus (Fichtel and Moll.)
24. Sorites duplex (Carpenter).
25. Discorbis sp.
26. Eponides sp.
27. Asterigerina carinata d'Orbigny.

28. Amphistegina lessonii d'Orbigny.
29. Globigerina sp.
30. Anomalina ammonoides (Reuss).
31. " sp.
32. Cibicides lobatula (Walker and Jacob).
33. " sp.
34. ?

Algae.

Dr. Marshall A. Howe who identified some of the algae found in the soils, states in a letter: "The fragments of algae shown in your sections appear to belong to genera such as occur in the Bermudian sea at the present time, e. g., *Neomeris, Halimeda* and *Amphiroa* and *Lithoporella melobesioides*. Other genera are doubtless present,—such as *Lithophyllum*,—representatives of which are now widely distributed from the tropics to the Arctic regions."

PETROLOGY AND CHEMISTRY.

Petrology.

The writer is greatly indebted to Professor Esper S. Larsen of Harvard University for a careful and detailed petrographic study of the fossil soils and eolianites. This investigation has consumed many days of Dr. Larsen's time, and I wish to take this opportunity of thanking him.

The petrologic study was undertaken for several reasons. In the first place, the nature of the insoluble residue in the soils is of interest. Secondly, it was thought that the mineralogical composition of this insoluble residue in the various soils might vary sufficiently to be an aid in correlation. Thirdly, the ratio of the weight percentage of insoluble residue in the soils to the weight percentage of insoluble residue in the eolianites gives, on certain assumptions, the number of feet of dissolved eolianite necessary to furnish one foot of soil.

Eolianites. Nine specimens of eolianite were studied and the results are compiled in Table V.[1] The insoluble residue ranges from 0.0004 % to 0.002 % of the total rock; the average is 0.0008 %.

The following procedure was employed in making the petrologic analyses of the soils and eolianites. From five to one thousand grams of the specimen—the exact amount depending on the character of the sample and the amount available—were treated with dilute hydrochloric acid until all the carbonate, and as much as possible of the iron oxide and other colloidal products, were dissolved. In the soils the

[1] Table V is a folder at the end of the paper.

insoluble residue consisted of sand grains and red clay. The amount of residue from the light-colored, purer soils was small, but from the red soils it reached fifty percent or more. The amount of sand was also greater in the red soils. The insoluble residue was rubbed between the fingers and the clay washed away with water. The sand grains were then studied under the microscope by the immersion method. For many samples the sand was divided into three or more parts with a strong electro-magnet before the microscopic study was undertaken. The method employed determines only minerals that are insoluble in dilute hydrochloric acid and coarser than silt size. The results of the petrographic study are shown in Table V. The estimated percentages of minerals are only rough approximations of weight percentage, as few careful estimates were made, and for many samples the small number of grains present—in some cases as few as two—gave results that can not be considered fair averages. Most of the grains were from 0.5 to 2 millimeters in size, but a few were as large as 3 millimeters and many were smaller than 0.5 millimeters. Some of the quartz grains are well-rounded, but the pyroxene and perovskite grains are mostly angular. On the pyroxene, spine-like projections parallel to the elongation were common. Usually the pyroxene was surprisingly fresh.

The average percentage of minerals found in the residue from the eolianites is given in Table VII.

Fossil soils. The results of thirty-seven petrographic analyses of the fossil soils are compiled in Table V and arranged according to localities. Table VI gives the range in composition of each soil and also the average composition. It also shows that the insoluble residue in the fossil soils ranges from 0.001 per cent to 4.3 per cent. The low percentages are from the light-colored soils; the high values from the deep-red soils.

Significance of the Petrology. From a study of Tables V, VI, and VII it is obvious that the individual analyses vary greatly. Undoubtedly the insoluble residue from any soil or eolianite is not uniform, but the differences actually found are in large part due to the small size of the samples studied. Although each original sample of eolianite weighed from five to a thousand grams, the number of sand grains remaining after treatment with acid was always very small, frequently fewer than five and seldom more than ten. The individual analyses, therefore, do not have any great significance. A study of the totals of several analyses, however, may give some valuable information.

TABLE VI. RANGE AND AVERAGE MINERAL COMPOSITION OF THE SOILS.[1]

	Shore Hills	Harrington	St. George's	Signal Hill	McGall's	Ave.
No. analyses	10	8	11	7	1	
Residue	0.003–4.3 0.650	0.001–1.01 0.004	0.001–0.2 0.073	0.001–0.02 0.003	0.02	
Quartz	7–100 43	0–60 32	3–87 25½	0–58 25	40	32
Pyroxene	0–50 12	0–75 36	0–70 25	0–70 43	6	27
Perovskite	0–67 30	0–30 16	tr–40 19	0–40 21	6	21
Magnetite	0–24 6	0–5 1	0–55 12	0–25 9	4	7
Orthoclase	0–5 ½	0–18 3	0–83 9½	0–10 1½	6	4
Glass	tr	0–40 5	0–45 5	0	38	3½
Titanite	0–7 2	0–30 5	0–5 1	tr		2
Brown Garnet	0–20 5	0	0–2 tr	0		1
Plagioclase	0	0–20 2	0–25 2	tr		1
Pink Garnet	0–2 ½	tr	0–7 1	tr		½
Misc.	Epidote Zircon Tourmaline Rutile Leucoxene Corundum Muscovite Cyanite Staurolite	Epidote Zircon	Zircon Biotite Spinel Chlorite	Zircon Biotite Hornblende		1 100

[1] Expressed in percentages.

Table VI shows that there are no systematic and constant differences in the mineralogy of the various soils. Any discrepancies are probably due to the limitations of the study. The relatively large amount of quartz and deficiency of pyroxene in the Shore Hills soil compared with the other soils are the only facts that may have any possible significance. But even these are of no great importance in correlation, for individual analyses vary tremendously from the average. The mineralogy of the fossil soils, as far as the work has gone, therefore, is of no great service in correlating the fossil soils, except in the case of the Shore Hills soil, where quartz is usually high.

In Table VII the mineralogy of the eolianites and fossil soils is compared. Column 1 gives the average composition of all the soil analyses; column 2, that of the eolianites. In general, the insoluble residues are seen to be similar. This is of course exactly what we should expect if the fossil soils were derived from the eolianites.

TABLE VII. Comparative Mineralogy of Average Soil and Average Eolianite.

	Soils (37 analyses)	Eolianites (9 analyses)
Quartz	32%	37%
Pyroxene	27	10
Perovskite	21	15½
Magnetite	7	5
Orthoclase	4	18½
Glass	3½	6
Titanite	2	tr
Brown Garnet	1	3½
Red Garnet	½	1
Hydrargillite?	0	3½
Plagioclase	1	0
Misc.	1	0
Total	100	100

To calculate how many feet of limestone have been weathered to produce one foot of soil involves many difficulties. The average amount of the insoluble residue in nine eolianites is 0.0008 %. The percentage of residue in the soils, however, varies greatly. In the light-colored soils on the hill slopes it ranges from 0.001 % to 0.005 %,

but such soils have lost much material due to rain-wash. In the deep-red soils of the pockets the residue is as much as 4.3 %, but a large amount of this material has probably been washed in from the surrounding slopes. A red soil developed on a flat surface, however, represents a strictly residual soil. The Shore Hills (?) soil at Pink Beach was developed under such conditions and the insoluble residue is 0.1 %; the Shore Hills soil from Grape Bay carries 0.05 % insoluble residue; four Red St. George's soil samples at St. George's gives an average of 0.08%. Assuming that the last figure is a fair average and dividing it by the percentage of insoluble residue in the eolianites (0.0008%) we conclude that one hundred cubic feet of limestone are destroyed to give one cubic foot of soil. A. E. Verrill (*1907*, p. 57) obtained a figure twice as great; that is, he calculated that to form one foot of soil two hundred feet of eolianite must be destroyed. Verrill does not state what method he employed, but it is probable that the present estimate is the more accurate. A foot of soil would form twice as fast as he estimated, that is, in 60,000 years instead of 120,000 years. Obviously all these figures have a large percentage of uncertainty and can be regarded only as approximations.

The question of the source of the minerals in the residue of the soils and eolianites introduces a new problem. Many of the more common minerals have obviously been derived from the volcanic platform. The perovskite, pyroxene, magnetite, titanite, biotite, and glass have all been described by L. V. Pirsson (*1914*) as occurring in the lavas. Although brown garnet is not mentioned by him, it is frequently found in such basic rocks. But the presence of such typically continental minerals as quartz, orthoclase, pink garnet, zircon, tourmaline, rutile, muscovite, hornblende, staurolite, and cyanite is quite unexpected in Bermuda. Clearly these minerals are not native to Bermuda and must have been introduced from elsewhere. Once arrived in Bermuda a grain of quartz would long preserve its volume and shape. It would suffer very little wear while drifting in sands composed largely of calcium carbonate. The high percentage of quartz is merely a function of its resistance to corrosion, and does not necessarily indicate an abundant supply. The quartz particles are well rounded, and it is safe to assume that much of the rounding, if not all, was produced elsewhere than in Bermuda.

I have no satisfactory solution of the source of these exotic minerals, but a number of possible explanations may be mentioned. (1) Large numbers of birds stop for a few days in Bermuda while on

their seasonal migrations between the West Indies and Nova Scotia.[1] Many birds carry a variety of sand grains in their crops and intestines. In the course of thousands of years a quantity of quartz grains and other continental minerals might well accumulate in this way to the amount found in Bermuda. (2) Dr. Arthur Keith has suggested to me that tropical hurricanes might be competent to transport sand from the Atlantic coastal plain to Bermuda. (3) Raymond and Stetson[2] have recently shown that a jelly-like organic substance may be a very effective agent in transporting sand grains, and I also suggest that the sargasso weed, so common on Bermuda shores, might have transported sand grains. I have found that sand, in which rounded grains are common, adheres firmly to that weed on Florida beaches.

Chemistry.

Two chemical analyses of the St. George's soil from Ferry Road, St. George's, are given below. They were made by Mrs. House. The first is that of a pink variant; the second, that of the deep-red phase taken from a hollow and composed largely of silica, alumina, iron, and water.

TABLE VIII. Chemistry of the Soils.

	Pink soil	Red soil
SiO_2	0.59%	28.68%
Al_2O_3	0.39	26.24
Fe_2O_3	0.36	12.09
MgO	1.00	1.72
CaO	50.81	3.13
Na_2O	1.21	0.77
K_2O	0.19	0.73
CO_2	39.56	2.03
TiO_2	tr	1.58
P_2O_5	0.01	0.50
SO_3	0.56	0.26
Cl	1.63	0.28
MnO	n.d.	0.25
H_2O	4.06	21.80
Organic Matter		
	100.37	100.06

[1] Bradlee, Thomas S., and Mowbray, Louis L. A List of Birds recorded from the Bermudas. With additional notes compiled by Warren F. Eaton. Proc. Boston Soc. Nat. Hist. vol. 39, no. 8, pp. 279–374. 1931. (In press.) Contrib. Ber. Biol. Sta. for Research. no. 164.

[2] P. E. Raymond and H. C. Stetson, A new factor in the transportation and distribution of marine sediments, Sci., vol. 73, pp. 105–106, 1931.

PHYSIOGRAPHY OF BERMUDA.

Older and Younger Bermuda.

In describing the topography of Bermuda, the lack of streams and river valleys has been mentioned. Throughout most of the islands the depressions are either sink-holes, due to the collapse of the roofs of caves, or are residual depressions left by the construction of encompassing sand dunes. Nevertheless, in the low lying northwest portion of Warwick parish, in the islands between Hamilton Harbor and Great Sound, in the Ireland Island group and in Pembroke parish the topography is of lower relief and more rolling than elsewhere. These relations may be well observed from the Gibbs' Hill lighthouse, which is built in a region of pronounced dune topography. A mile to the north, across Riddle's Bay, is the Riddle's Bay golf course, where the subdued, rolling topography is in striking contrast to the dune topography of the coasts. Two miles to the north are the islands of the Sounds, and they likewise have a low, rolling surface. In the vicinity of the city of Hamilton similar conditions prevail. The north shore portrays a typical dune topography, but to the northwest of Pembroke Marsh there are areas with subdued surfaces.

In general the rocks underlying these areas of low, rolling relief belong to the older stratigraphic horizons, particularly the Walsingham and Pembroke eolianites, the Belmont and Devonshire marine limestones, and the Shore Hills-Harrington soil. These regions are obviously places where the younger dunes did not arise to any great extent. They are part of the old degraded nucleus of Bermuda, about which the younger dunes have accumulated. A glance at the topographic map of Bermuda (Plate XIV) shows this older Bermuda, forming a partially submerged core and flanked on both the north and south by the younger dunes.

The direction in which the younger dunes have migrated can be determined from the dip of the cross-bedding. On the windward side of a dune the cross-bedding dips about five to twelve degrees, on the leeward side, about thirty degrees. On the south shore of Bermuda, in Warwick and Southampton parishes, the steeper cross-bedding dips northeasterly, indicating that the dunes were migrating toward the northeast. The dunes on the north shore of Pembroke parish, on the other hand, have migrated toward the south. In other words, the dunes on opposite sides of the islands were moving inland toward each other. The direction in which dunes migrate is not primarily a

function of the prevailing winds, but is in part controlled by the source of supply. Obviously sand must migrate away from its source.

The present Bermuda has therefore evolved from a much smaller, older Bermuda by a process of accretion. The older Bermuda is now best displayed in regions such as that around Hamilton, in the Walsingham Cave district, in the islands of the Sound, and in northern Warwick. To this original nucleus, reduced by a long interval of subaerial erosion, have been added the younger dunes, which have migrated inland from either coast. This younger Bermuda extends the length of the north and south shores.

Marine Benches.

The marine benches are another feature of special interest in the physiography of Bermuda. The most conspicuous, stand between eight and twelve feet above sea-level. They are well displayed at Grape Bay, Hungry Bay, McGall's Bay, Spanish Rock, and many other places. Daly[1] has called attention to this feature on many coasts and regards it as due to a very recent, negative, eustatic shift of sea-level. A bench 25 feet above sea-level is well exposed at Mangrove Bay. A sea-cave on the east side of St. David's Head, to the east of the lighthouse, also indicates this level.

Caves of Bermuda.

The caves are most conspicuously developed in the Walsingham district, between Castle Harbor and Harrington Sound. They have recently been described by Swinnerton.[2] "The accessible parts are not over a few hundred yards in length, although it is undoubtedly true that a network of passages underlies much of the cave area. The presence of sea water in the caves, the variously colored deposits stained with orange cave-earth, and fossil soils, contrasted with the many brilliant white stalactites and stalagmites, make the caves extremely picturesque and memorable spots for the tourist to visit and likewise for the geologist to study. . . . Primarily the caves are zones of solution by downward migrating rain-water along steeply dipping and intersecting joints in the compact Walsingham limestone."

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[1] R. A. Daly, Recent world-wide sinking of ocean level. Bull. Geol. Soc. America, vol. 31, p. 112, 1920.

[2] A. C. Swinnerton, The Caves of Bermuda, Bull. Geol. Soc. America, vol. 40, p. 194, 1929.

The bottom of some of the caves is fifty or sixty feet below sea-level, a fact of great significance, indicating shifts in the water table. Stalactites and stalagmites are abundant below sea-level, but unfortunately no figure is given concerning the exact limits. In 1869, while blasting in Hamilton Harbor, stalactites were found at a depth of 30 feet. Swinnerton has concluded from studies in Kentucky and Bermuda that limestone caves are not cut below the water table and that in general caves form most readily just above that level. The Bermuda caves originated, therefore, when the water table was approximately sixty feet lower than now. On a small island of porous limestone, such as Bermuda, the water table is essentially equivalent to sea-level. Hence these caves show that at some time or times in the past, sea-level was sixty feet or more lower than it is now. No evidence has yet been obtained as to the number of such periods of low water.

The depth of water in the caves and on the outer part of the Bermuda platform is about the same. In the caves the water is fifty to sixty feet deep. The Bermuda platform, extending beyond the actual shores, out to distances ranging from one to three miles, lies at a depth of 65 to 75 feet. This correspondence is suggestive of a prolonged period during which sea-level was depressed to about the amount stated.

EVOLUTION OF BERMUDA.

Recapitulation of Significant Facts.

A brief recapitulation of the significant facts is essential before considering the evolution of Bermuda. What facts are important and what are not, is partly a matter of judgment. What appear to be the significant facts are listed and any deduced sequence of events must satisfy these.

(1) Modern Bermuda is built on a volcanic platform. The top of this platform is elliptical in outline, has an area of 250 square miles, and at the site of the well-boring is about 245 feet below sea-level. (2) Resting on this platform is limestone, several hundred feet thick. The rock is dominantly eolianite, with minor quantities of marine limestone, fossil soils, sand-rock, and calcareous ooze. The thickest part of the limestone is in the form of a great ellipse about thirty miles in its greatest dimension and from one to ten miles broad. The southeast sector of this ring projects above water and is modern Bermuda, which has an area of 19¼ square miles. (3) Interbedded

with the eolianites are five fossil soils. (4) The two lower soils, Shore Hills and Harrington, are at many places separated by a marine limestone, the Devonshire, which implies one period of soil formation interrupted by a marine stage. The lower of these two soils, the Shore Hills, is mostly a residual soil, in places four feet thick. For its accumulation 200,000 or more years were necessary. The upper soil, the Harrington, is partly a soil of accretion and probably accumulated with some rapidity. (5) The third soil, the St. George's, also a residual soil, is about two feet thick, and took something like 150,000 years to form. The upper two soils, Signal Hill and McGall's, are very light-colored and in their upper parts are soils of accretion. No very exact estimate can be made of the length of time essential for them to form, but a few thousands or tens of thousands of years would probably suffice. (7) Associated with the Shore Hills and Harrington soils are two thin beds of marine limestone, the Belmont and Devonshire. (8) Numerous changes of level have taken place. Evidence from the caves alone indicates that sea-level has at some time been at least sixty feet lower than at present. The eolian material in the deep boring, extending as it does to a depth of at least 225 feet below sea-level, would indicate that the ocean level stood much lower than the evidence from the caves alone gives us. The marine limestones show that sea-level has stood at least twenty-five feet higher than now. (9) Eolianite-forming periods and soil-forming periods have alternated. (10) Eolianite is not forming today on any notable scale, but a soil is slowly thickening. A corollary is that the fossil soils formed under conditions largely similar to those now existing in Bermuda, the eolianites under conditions very different. (11) The geological age of the rocks is not strictly demonstrable. The volcanics are Tertiary or earlier, the eolianites and soils presumably all Pleistocene.

Inadequacy of Subsidence Hypothesis.

Earlier workers in Bermuda, impressed by the submerged caves and forests, and realizing that the eolianites must have formed when the island was much larger, have invoked the idea of subsidence—that is, that the Bermuda volcano has gradually sunk beneath the ocean waves. Submerged forests and caves were thus explained. The eolianites might also be explained on this hypothesis, having been formed when Bermuda stood relatively high and the land surface was larger. Such an hypothesis was competent to account for the few facts available thirty to fifty years ago.

But the interbedding of fossil soils with the eolianites was then not properly allowed for in the theory of the case. This paper has its main purpose in stressing a quite different picture of the evolution, soon to be more expressly stated. According to this new hypothesis, the eolianites were developed under low-water conditions; the fossil soils under high-water conditions. It will also appear highly probable that not one of the high-water stages represents sinking of Bermuda. On the other hand, each of these stages is correlated with an eustatic (world-wide) shift of sea-level.

Pleistocene Oscillations of Sea-level.

A feasible explanation of such changes of level is available. All geologists agree that during maximum glaciation sea-level must have stood much lower than at present (Fig. 18). During the Tertiary, when the Greenland and Antarctic ice-caps presumably did not exist, sea-level must have stood higher. Moreover, we know that glaciation was multiple. Hence during the Pleistocene there must have been oscillations of sea-level, high-water stages alternating with low-water stages. The ranges of the fluctuation of sea-level are of the right order for this Bermuda case, and equally important, their geological dates are also appropriate. Where so many correspondences exist, the new theory seems much better supported than is any theory involving vertical displacements (repeated up-and-down movements) of Bermuda.

Daly[1] has recently summarized the present status of our knowledge concerning the changes in level due to glaciation and deglaciation. He has also emphasized certain complexities entering into the problem because of distortion of the solid earth geoid due to plastic flow, elastic effects, and the gravitative attraction of the ice caps. Daly (1929, p. 727) concludes that "when the Wisconsin-Würm ice-caps were of full size, the sea-level over most of the earth was not far from eighty meters (262 feet) lower than at present. In late Tertiary time, if the Greenland and Antarctic ice-caps were nonexistent, sea-level was presumably 26 to 52 meters (85 to 170 feet) higher than now.

Origin of Fossil Soils and Eolianites.

Bermuda is now a land of luxuriant vegetation, and a soil similar to the fossil soils is forming. Modern dunes are rare and in nearly all

[1] R. A. Daly, Swinging Sea Level of the Ice Age, Bull. Geol. Soc. America, vol. 40, pp. 721–734, 1929.

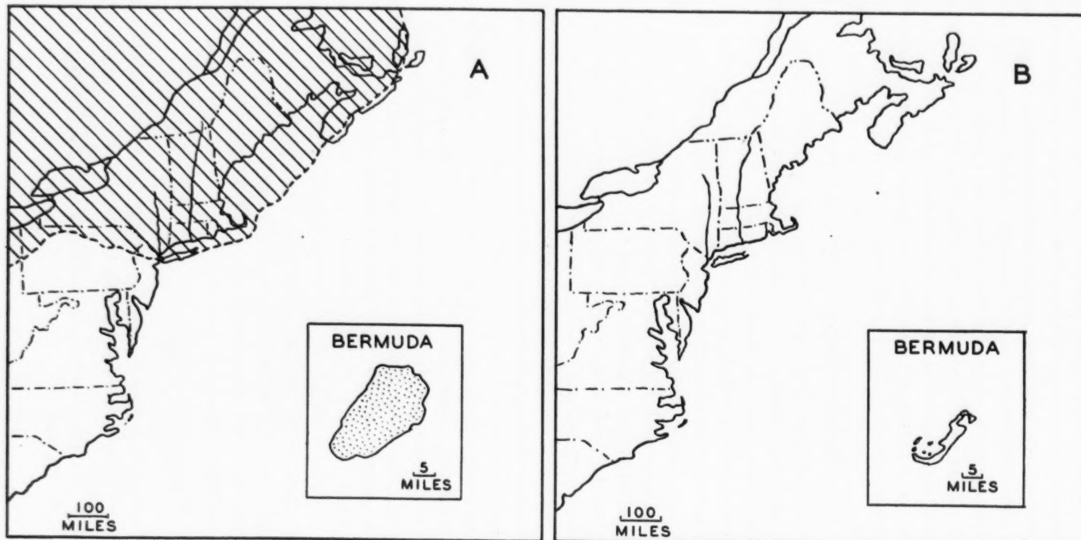

FIGURE 18. A. Bermuda enlarged during glaciations. B. Bermuda reduced during deglaciations. (After Swinnerton.)

cases are the result of deforestation by man. The fossil soils were doubtless formed under conditions not unlike those ruling Bermuda today. The truly residual fossil soils, particularly the Shore Hills, might well be the product of long periods of weathering in the interglacial ages. But the eolianites must have formed under vastly different conditions from those now existing in Bermuda. They are witnesses of a different climate. Can they be correlated with glacial stages of the Pleistocene Ice Age?

The Bermuda *reef* encloses a great lagoon, the floor of which, even in its deepest part, is only about sixty feet deep. The reef is also surrounded by a bench, one to three miles wide and about seventy feet below sea-level. As the water surface fell because of glaciation on the continents, more and more of Bermuda was exposed to the winds. At stages, when sea-level had dropped, great flats covered by marine shells were exposed to the air. Strong winds sweeping across the now dry, but naturally little vegetated flats, would be likely to drift great quantities of broken shells, to pile up as dunes. Even when the continental glaciers had reached a third or half their total size the whole Bermuda platform would stand above the sea. Throughout the tens of thousands of years that the ice-front was moving south, while it was standing at its maximum extent, and again while it was retreating, the Bermuda platform was emergent.

That the Pleistocene vegetative cover hindered this growth of dunes in but slight degree, is a natural assumption. For thousands of years there was no soil on the broad, emerged flat. Hence the establishment of a binding mantle of vegetation on the sands was there practically impossible. Moreover, with the increased cold at Bermuda, many indigenous plants must have been inhibited from vigorous growth. I believe that in certain protected places, like the Walsingham cave district, plant growth went on during eolianite-forming stages.

Furthermore, the Pleistocene winds of Bermuda must have been much stronger than those at present. When the continents were covered with great ice-caps and their accompanying anticyclones, the storm tracks must have been pushed farther south. This meant more wind and also a colder climate.

In summary, the eolianites were certainly formed under climatic and topographic conditions different from those now existing. The eolianite epochs alternated with the soil-forming epochs. The glacial and interglacial stages of the Pleistocene also represent a series of alternating climatic conditions and it seems logical to associate the two. More-

over, if we assume that the eolianites are contemporaneous with the glacial stages, we have a satisfactory explanation of the abundance of available calcareous sand, the high winds, and the dearth of vegetation, all of which are conditions favorable to the formation of sand dunes.

Subdivisions of the Pleistocene.

The Pleistocene deposits of North America have been recently classified by Leighton[1] as shown in the accompanying table. Many attempts have been made to estimate the relative and absolute lengths of the interglacial stages. The most recent, that by Professor George F. Kay, has not been published, but he has very kindly discussed this problem with the writer. His figures for relative lengths of the interglacial stages and sub-stages, are given in a column at the right, post-Wisconsin time being taken as unity.

TABLE IX. Classifications of the Pleistocene.

A. *North America.*

		Relative length
Recent		1
IV. Wisconsin Glacial	Hudsonian sub-stage of advance (late Wisconsin)	
	Unnamed sub-stage of recession	¼
	Quebecan (Early and Middle Wisconsin) sub-stage of advance	
	Peorian sub-stage of recession	¼
	Manitoban (Iowan) sub-stage of advance	
Sangamon interglacial		6
III. Illinoian Glacial		
Yarmouth interglacial		12
II. Kansan Glacial		
Aftonian interglacial		8
I. Nebraskan Glacial		

B. *The Alps.*

Penck and Brückner[2] give the following classification for the Alps:

IV. Würm Glacial (three-fold)
Riss-Würm interglacial
III. Riss Glacial
Mindel-Riss interglacial
II. Mindel Glacial
Günz-Mindel interglacial
I. Günz Glacial

[1] M. W. Leighton, The Peorian loess and the classification of the glacial drift sheets of the Mississippi Valley, Jour. Geol., vol. 39, pp. 45–53, 1931.

[2] Penck und Brückner: Die Alpen in Eiszeitalter, 1909.

Both classifications agree in recognizing four glacial stages separated by three interglacial stages, the last glacial stage being three-fold, though the American classification is here the more detailed. Kay[1] has suggested calling the last glacial stage the Eldoran, to be subdivided into four sub-stages of advance, the Iowan, Early, Middle and Late Wisconsin, and three sub-stages of recession. Leighton's three-fold classification is the one adopted in this paper. There is no reason to suppose that the continental ice-cap completely melted away at any time during the Wisconsin, but there were obviously great changes in the amount of ice. These oscillations undoubtedly caused shifts in sea-level and were themselves the product of climatic changes which may well have been felt in Bermuda.

In our discussion, Kay stated that the amount of leaching of calcium carbonate during the various interglacial stages has been as follows: Aftonian, 20 feet; Yarmouth, 30 feet; Sangamon, 12 feet; post-Wisconsin, 2½ feet. Assuming that post-glacial time is 25,000 years[2] and that the rapidity of leaching does not vary with depth—which is undoubtedly not strictly correct—we would conclude that the Aftonian lasted 200,000 years, the Yarmouth 300,000, the Sangamon 120,000. For the sub-stages of recession of the Wisconsin (Eldoran) no direct evidence is available, but from indirect evidence they must have been very short, perhaps 5,000 years or less each. The relative length of the various interglacial stages of recession and sub-stages of advance, as thus determined, is entered in Table IX, A.

Correlation of Bermuda with North America.

The attempt to correlate the Pleistocene deposits of Bermuda with those of North America is exceedingly hazardous. The fossil snails are certainly of no value in this problem, and the marine fossils of the Belmont and Devonshire marine formations likewise apparently give no help. Only one method is available. If the reader accepts the contention of the writer that the eolianites represent glacial stages and the fossil soils interglacial stages, the relative and absolute length of the interglacial stages in Bermuda may be compared with those of North America. The fundamental assumption is made, of course, that whatever major changes took place in the ice-caps had their effect

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[1] Personal communication.

[2] George F. Kay, The relative ages of the Iowa and Wisconsin drift sheets, Am. Jour. Sci., vol. 21, pp. 158–172, 1931.

in Bermuda. In the accompanying table (X) the stratigraphic data for Bermuda are placed in one column. In the next column is indicated the nature of the conditions under which the formation was deposited. The approximate length of time represented by each soil—that is, interglacial stage—is indicated and, finally, the relative length of the interglacial stages, taking post-Southampton time as unity.

TABLE X. PLEISTOCENE IN BERMUDA.

Formation Name	*Conditions*	*Length in yrs.*	*Relative length*
Present soil	*Post-glacial*	25,000	1
Southampton eolianite	Glacial		
McGall's soil	*Interglacial*	10,000 ?	2/5?
Somerset eolianite	Glacial		
Signal Hill soil	*Interglacial*	10,000 ?	2/5?
Warwick eolianite	Glacial		
St. George's soil	*Interglacial*	120,000	6
Pembroke eolianite	Glacial		
Harrington soil Devonshire limestone Shore Hills soil Belmont limestone	*Interglacial*	250,000	10
Walsingham eolianite	Glacial		

This table may be compared with that of North America in several ways. One method is to correlate the longest interglacial age of which we have any record in Bermuda with the longest in North America—that is, to correlate the Belmont-Shore Hills-Devonshire-Harrington group with the Yarmouth. This method leads to the correlation shown in the following table. A second method is to compare the relative lengths of the interglacial ages. This leads to a similar result. The correlation of Bermuda with North America would then be as follows:

TABLE XI. CORRELATION OF BERMUDA WITH NORTH AMERICA.

	North America	*Bermuda*
Wisconsin	Hudsonian sub-stage of advance	Southampton eolianite
Wisconsin	*Unnamed sub-stage of recession*	*McGall's soil*
Wisconsin	Quebecan sub-stage of advance	Somerset eolianite
Wisconsin	*Peorian sub-stage of recession*	*Signal Hill soil*
Wisconsin	Manitoban glacial	Warwick eolianite
Sangamon interglacial		*St. George's soil*

Illinoian glacial	Pembroke eolianite
Yarmouth interglacial	*Harrington soil* *Devonshire limestone* *Shore Hills soil* *Belmont limestone*
Kansan glacial	Walsingham eolianite
Aftonian interglacial	*Part of Walsingham?*
Nebraskan glacial	Part of Walsingham?

The physiography of Bermuda supplies a very weighty argument supporting the correlation given above. The dune topography of the Warwick, Somerset, and Southampton eolianites is well preserved both on the north and south shores. The dune topography of the Pembroke and Walsingham eolianites, on the other hand, has been completely destroyed, as in the vicinity of Hamilton and Riddle's Bay. It is well known that in continental North America post-Wisconsin time has been so short that the topography of glacial deposits of Wisconsin age is well preserved. The original topography of Illinoian deposits, however, is more or less completely destroyed. If these relations hold in Bermuda, we would conclude that the eolianites with well-preserved dune topography—the Warwick, Somerset, and Southampton—are Wisconsin. Eolianites on which the dune topography is lacking, such as the Pembroke and Walsingham, are by the same criteria pre-Wisconsin.

Not only does the correlation satisfy the requirements imposed by the relative lengths of the various interglacial and sub-glacial stages, but it also indicates that there was unusually high water during the Yarmouth. This is in accord with evidence elsewhere. The fauna and flora found in the Yarmouth interglacial deposits near Toronto[1] indicate a stage warmer than the present. As a corollary we might conclude that the Greenland and Antarctic ice-caps were not as large as now and that therefore sea-level stood higher.

The conclusion has been reached that the Walsingham eolianite represents the Kansan glacial stage and possibly the Aftonian interglacial and the Nebraskan glacial. The problem has not yet been solved, but there are several possible solutions. (1) The Aftonian soil may be present but not exposed. (2) Bermuda may not have been high enough during the Aftonian to project above sea-level. (3) Aftonian soil may have been formed but later destroyed. Of these suggestions, the second seems the most reasonable. The failure to

[1] A. P. Coleman, Ice Ages, Recent and Ancient.

identify definitely Aftonian and Nebraskan deposits by no means invalidates the correlation, any more than the failure to identify Pre-Cambrian rocks in the Mississippi Valley invalidates the identification of the Paleozoic rocks.

Cutting of the Bermuda Platform.

In the earlier pages it has been assumed that the volcanic platform of Bermuda is elliptical in ground-plan, with an area of about two hundred square miles, and essentially flat, the depth being about 245 feet below sea-level. On this platform repose the eolian limestones of Bermuda. Is the surface of this platform a product of Tertiary marine planation or has it been greatly reduced by the Pleistocene waves? Daly[1] has shown that during Tertiary time, when the Antarctic and Greenland ice-caps were presumably non-existent, the strand-line in the vicinity of such oceanic islands as Bermuda was from 35 to 40 meters (115 to 131 feet) higher than now. At the time of maximum glaciation sea-level was about 80 meters (262 feet) lower than at present.

According to Barrell[2] the profile of equilibrium on a stormy sea shelf is about 300 feet below sea-level. The Bermuda platform, 245 feet below present sea-level, would be from 360 to 375 feet below the surface of the Tertiary ocean and 20 feet above the lowest Pleistocene sea-level. Obviously these figures are only approximations, but they readily accord with the hypothesis that the Bermuda platform was base-leveled during the Tertiary. If the volcano had become extinct in early Tertiary time, by the end of the Tertiary it might readily have been reduced to the base-level of marine erosion, which must be at least three hundred feet below sea-level on an isolated and exposed oceanic island. Marine planation during the maximum extent of the Pleistocene ice sheets would have reduced Bermuda to a much lower platform than that now existing. We are thus forced to conclude that Tertiary planation was fully competent to form the Bermuda platform, but that Pleistocene planation would have formed a lower surface.

There is an even more weighty argument in favor of Tertiary planation. Eolianites and fossil soils from many early glacial and

[1] R. A. Daly, Swinging sea level of the Ice Age, Bull. Geol. Soc. America, vol. 40, pp. 721–734, 1929.

[2] Joseph Barrell, The piedmont terraces of the northern Appalachians, Am. Jour. Sci., vol. 49, p. 354, 1920.

interglacial stages have been preserved in Bermuda. If Pleistocene marine planation were competent to actively erode and reduce the volcanic platform during each time of maximum ice advance, the superficial eolianites and soils would be the first to be destroyed. The very preservation of Kansan and Illinoian eolianites and Yarmouth and Sangamon soils during successive glacial and interglacial stages shows that the Pleistocene waves were not even competent to destroy all the superficial deposits, much less to erode the volcanic platform. Once again we are driven to the conclusion that the Bermuda volcanic platform was reduced to its present depth in pre-Pleistocene time.

Observations on the Location of the Bermuda Islands on the South and Southeast Edge of the Volcanic Platform.

It may be noted that the main mass of the Bermuda Islands is located on the south and southeast sides of the Bermuda platform. The reason for this arrangement has not heretofore been satisfactorily explained. To leave this question without any attempt at an explanation, would not be satisfactory, especially as I believe it is possible to throw some light on it, even though what now seems like light may eventually prove to be inapplicable to the problem in hand.

A glance at the map of Bermuda will show that the islands as a group have a northeast trend. The directions of the dips in the dunes prove that for the greater part of the south and southwest parts of the islands the wind came from the southwest. It is true that on the "north shore" of the main Bermuda island the dunes show that the winds came from the north or northeast, and that on the easternmost part of the island they came from the northeast. Still, it remains true that for the greater part the winds came from the southwest, and not directly on shore from the south. In other words the winds which formed the dunes did not come directly on shore, but at an angle of about 45°. If the winds were from the southwest during glacial stages the greatest amount of land building would be at the southwest, as it is in Southampton and Somerset. The main island has been built onto, somewhat like shingles on a roof in a southerly and southwesterly direction. As one goes northeast from Simmons Beach it is seen that the dune formations are progressively thinner in that direction.

Cressey[1] has shown, in his study of the dunes of Lake Michigan, that

[1] George B. Cressey; The Indiana Sand Dunes and Shore Line of Lake Michigan Basin, The Geog. Soc. of Chicago, Bull. No. 8, May 1928.

the oldest dunes are several miles back from the present lake front and the youngest dunes are at the present shoreline of the lake. As the lake shrank in size the dune building followed the receding waters. It is believed that the same thing happened at Bermuda, and the structure of the islands themselves lends support to this belief.

In other words, I believe that the optimum location for dune building, which would mean the largest dunes, would be·at the south and southwest parts of the islands, especially the main island. North and northwest winds might have been too strong for the preservation of dunes made on the northern rim of the platform. That dunes were there is proved by the remnants at North Rock. As the waters receded, after an interglacial stage, the dunes would follow them towards the new shoreline at a lower level. Here dunes would be built, but only to be destroyed as the waters returned with an onset of glacial conditions on the continents. The place best fitted for the preservation of dunes, and also the greatest height of dunes would be just where they are located today, not at the north or northwest or northeast—where strong anticyclonic winds from the continental ice sheets would destroy any dunes—but at the south or southwest, where that which had been built could have an opportunity to persist through the battle between the winds and dunes. That they were preserved at all, is probably due to the very quick cementation which takes place when this eolian shell sand is exposed to the atmosphere. Although not hard, the dunes would be able to offer more resistance to the attack of the waves than would be the case with quartz sand, where cementation could not be affected. By the time the waves reached the centre of the platform the cementation would have reached such a stage that resistance would be considerable and thus the life of the Bermuda group would be extended for a much longer period than with quartz sand.

Turning now to the Bahama Islands, what do we see? Exactly the same conditions. Take, for example, a few of the more northern islands of this group; Long Island, Cat Island, Eleuthera Island, Nassau, Great Abaco Island, Andros Island and Bahama Island, are located distinctly on the south and southeast of their platforms. The northern parts of the platforms are mostly free from islands. Why? The answer has already been given, I believe. The northern winds were too strong for the dunes of eolianite at the Bahamas, as well as at Bermuda, for such relatively soft rocks to endure the strength of the waves. The waves from the south and southwest were strong enough

for building good-sized dunes, but not so strong as to destroy them during the glacial stages, or late glacial stage when the waters came back from the ice, released by melting. There is an opportunity here to base a study of the winds of the Pleistocene on the location, size and structure of the dunes.

The evidence that the north winds were severe at Bermuda is indicated by the large dune, Prospect Hill, built parallel to north winds, which separates Pembroke and Devonshire marshes. Here we have a dune of Southampton or Somerset age, built from the north, which cuts across the direction in which were built the other dunes along the north shore. Very strong winds are known to build dunes parallel to their direction, as in this case. In no other part of Bermuda have I found a case similar to this. If there were other cases of the kind, it is to be presumed that such dunes were built on the northern part of the platform and not on the southern part and that they have been destroyed.

It is known that dunes protect the country farther away from the water than themselves. This is evidenced at Provincetown, on Cape Cod. Here, as one enters the town, is a pond about a mile east of the town. The pond has not yet filled but has been protected by the dunes on its northeast border, and has been in its present state as long as anyone can remember. Such must have been the case also at Bermuda. Parts were protected, and during long intervals, especially as the islands grew in height, the protection afforded by the high dunes would insure them from burial. As has already been noted, this has been especially true in the Walsingham cave district and about Hamilton and among the inner islands.

Not only in Bermuda, therefore, but in the Bahama group as well, the islands are located where the winds were most favorable for their growth and later protection. That this location was at the south and southwest, and not at the north and northwest, is indicated by the actual locations of the islands of both groups, the Bermudas and the Bahamas.

Summary of Geologic History of Bermuda.

The Bermuda volcanoes were erupted during the Tertiary, or earlier. By the end of the Tertiary they had been reduced to submarine platforms. The most northeasterly and largest of these was elliptical in plan, essentially flat, and several hundred feet below sea-level. With the coming of the Pleistocene great quantities of water were subtracted from the oceans to form the continental ice-sheets.

When the ice was at its maximum extent the strand-line fell as much as 260 feet below modern sea-level. While the ice-cap grew, large parts of the Bermuda banks, covered by mollusc shells and unprotected by vegetation, were exposed to the sweep of the winds and the dried sands were piled up in great dunes. The higher winds in the vicinity of the Bermuda of the Ice Age and the inevitable changes in flora were important factors favorable for the construction of dunes. When the sea rose at the close of each glacial stage, the source of supply for the dunes was buried beneath the ocean waves, the winds became less violent, and a permanent flora anchored the dunes. A long period of slow decay began, during which red and brown soils accumulated. Such conditions lasted for tens of thousands of years. But with the advent of a new glacial stage, conditions were once more favorable to the formation of dunes. Thus dune- and soil-forming conditions alternated during the Pleistocene.

The early Pleistocene history, as elsewhere in the world, is obscure. Eolianites formed during the Nebraskan glacial stage and a soil of Aftonian age have not yet been recognized in Bermuda. They may be present beneath the zone of observation, or Aftonian Bermuda may not have projected above the sea. During the Kansan stage the Walsingham eolianite was deposited as great dunes, which even today extend scores of feet above the level of the sea. With the advent of the long Yarmouth interglacial age, sea-level rose even higher than it is today and the Belmont marine limestone was deposited. Meantime on the emerged part of Bermuda the Shore Hills soil began to accumulate, and, with a slight fall of sea-level, weathering of the Belmont marine limestone began. Sea-level again rose and the Devonshire marine limestone was laid down. During the transition between the Yarmouth and the Illinoian, a new soil, the Harrington, was formed, but it was largely a soil of accretion, due to the increased activity of the wind. When the Illinoian glacial stage was in full swing the Pembroke eolianite was deposited. The Older Bermuda, the nucleus of the Younger Bermuda, had now formed. During the Sangamon interglacial stage, which was considerably shorter than the preceding Yarmouth interval of warmth, that part of Bermuda already formed was reduced to a low rolling topography. The St. George's soil formed during this stage is by no means as thick as that formed during the Yarmouth. The Sangamon was succeeded by the three-fold Wisconsin stage, which opened with the Manitoban (Iowan) glaciation, during which the Warwick eolianite was deposited. In the brief Peorian

sub-stage of recession, in the course of which the continental ice-sheets probably did not completely melt away, the Signal Hill soil was formed. Although a red soil washed into local pockets by the rain accumulated to some extent, the deposit of this time was dominantly a fine-grained, wind-blown material, most of which was presumably deposited when conditions were changing between glacial and interglacial. With the next great forward push of the ice, the Quebecan (Early and Middle Wisconsin), dune-forming conditions once more held sway on Bermuda and the Somerset eolianite was deposited. It was largely confined to the north and south shores, as in the case of the Warwick eolianite. Again the ice-caps retreated to the north, and another short unnamed sub-stage of recession ensued. The McGall's soil, dominantly a product of accretion, was rapidly deposited at this time. While the ice-caps were making the last great drive toward the south during the Hudsonian (Late Wisconsin), the Southampton eolianite accumulated on the coasts of Bermuda. With the final melting of the ice-caps, the water returned to the ocean, caused the sea-level to rise, and the Bermuda plateau, now provided with much new dry land, completed by the dunes of the Wisconsin stage, assumed its present appearance. The shorelines have been driven back somewhat by erosion. A twelve-foot drop in sea-level is recorded by an emerged bench, cut in geologically very recent time, perhaps during the time of written history.

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KEY TO SOIL LOCALITIES ON MAP

Soil No.	*Location*	*Soil No.*	*Location*	*Soil No.*	*Location*	*Soil No.*	*Location*	*Soil No.*	*Location*
1.	S–2	29.	H–4	56.	H–5	84.	K–L–5	112.	G–6
2.	S–2	30.	H–4	57.	I–5–6	85.	K–L–5	113.	G–6
3.	S–2	31.	H–5	58.	I–6	86.	K–L–5	114.	G–7
4.	S–2	32.	H–I–5	59.	H–5	87.	P–5	115.	G–H–7
5.	S–2	33.	F–7	60.	T–5	88.	D–6	116.	G–7
6.	S–2	34.	E–6	61.	M–4	89.	Q–R–2	117.	H–7
7.	S–2	35.	E–6	62.	L–5	90.	G–1	118.	M–5
8.	S–2	36.	F–6	63.	L–5	91.	L–6	119.	M–5
9.	R–2	37.	G–6	64.	L–6	92.	B–C–2	120.	M–4
10.	R–2	38.	F–7	65.	L–6	93.	I–5	121.	F–1
11.	R–2	39.	E–7	66.	L–6	94.	I–5	122.	P–4–5
12.	R–3	40.	D–E–6	67.	L–6	95.	I–5	123.	P–5
13.	M–6	41.	I–6	68.	L–6	96.	I–5	124.	G–6
14.	M–6	42.	C–D–6	69.	L–6	97.	D–1	125.	G–6
15.	N–6	43.	C–6	70.	L–6	98.	I–5	126.	G–5
16.	N–6	44.	C–6	71.	L–6	99.	D–1	127.	C–4
17.	N–6	45.	H–6	72.	L–6	100.	E–7	128.	E–5
18.	M–N–4	46.	D–2	73.	L–6	101.	E–6	129.	C–6
19.	N–3	47.	C–D–2	74.	L–6	102.	G–6	130.	I–7
20.	O–3	48.	C–D–2	75.	L–6	103.	G–7	131.	P–Q–6
21.	Q–6	49.	D–6	76.	L–M–6	104.	F–G–5	132.	P–4–5
22.	Q–6	50a.	H–7	77.	L–M–6	105.	G–5–6	133.	J–7
23.	T–3	50b.	H–7	78.	L–M–6	106.	G–7		
24.	R–3	51.	D–7	79.	K–6	107.	O–6		
25.	I–6	52.	H–5	80.	K–6	108.	G–7		
26.	J–6	53.	H–5	81.	K–6	109.	G–7		
27.	G–H–4	54.	H–5	82.	K–5	110.	S–2		
28.	H–4	55.	H–5	83.	K–L–5	111.	G–6		

Parishes

DE. = Devonshire	PE. = Pembroke	STG. = St. George's
HA. = Hamilton	SM. = Smith's	—— = Sandy's
PA. = Paget	SO. = Southampton	WA. = Warwick

PLATE 1.

1. A view of Bermuda looking east from the top of Gibbs' Hill lighthouse, about 370 feet above sea-level. Gibbs' Hill is about 246 feet above sea-level. The older Bermuda is seen on the left in the lowland about Riddles' Bay golf course and farther east. On the right are the much younger hills of eolianite deposited on the eroded Pembroke surface, and according to the theory advanced in this paper, dating from the Warwick stage of dune formation, and this in turn is correlated with the Iowan stage of the Pleistocene. At the low-water glacial stages, dunes to the north and south are thought to have formed and protected this region from these later dunes. These later southern dunes never extended farther north than the northern base of Gibbs' Hill.

2. View looking north from the top of Gibbs' Hill lighthouse, showing old lands of the Pembroke-St. George's stages, and eroded to its present form since that time. The islands in the foreground owe their shapes to erosion. The erosion must have taken place as much during the glacial stages of lowered ocean level as during the interglacial high water phases. The finding, by divers, of a cave with stalactites and red earth, in the ship channel in Hamilton harbour, at a depth of 6 fathoms, would necessitate a lowered sea-level or an uplifted Bermuda.

1

2

PLATE 2.

1. A typical close-up view of a fossil soil. The white objects are mainly *Poecilozonites bermudensis,* the most common extinct land snail in Bermuda. This photograph was taken in 1924 at Ruth's point, on St. David's island. The soil is probably of Harrington age. Map locality 60.

2. The deeply weathered fossil soil on Elliott Street, Hamilton. It is thought to be the St. George's soil resting on Pembroke eolianite. The solution pocket close to the writer is 5 feet deep below the soil proper. This soil is of a deep reddish-brown color. Fossil land snails were not found in this soil. A small piece of carbonized wood was found. In the most thoroughly weathered fossil soils the shells are usually absent or so much decomposed as to yield only fragments. Note the manner in which this soil merges with the more recent soil on the left.

Locality 98.

1

2

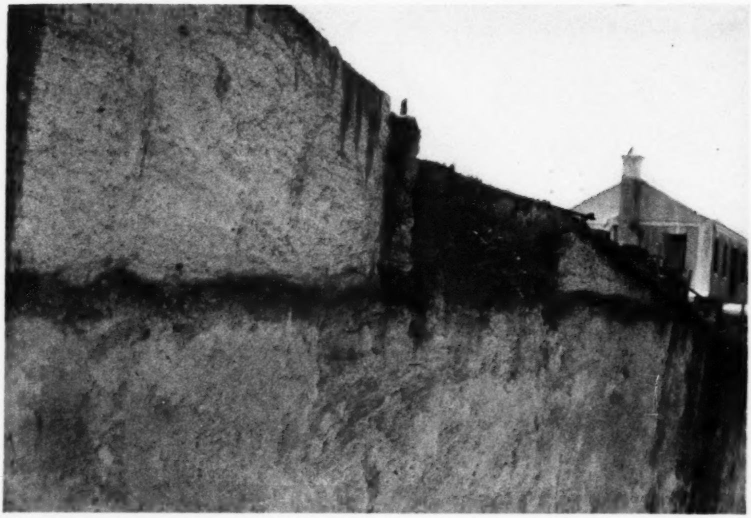
PLATE 3.

Professor T. H. Clark shown close to the pocket mentioned in the description of Pl. 2, No. 2.

Locality 98.

PLATE 4.

1. and 2. A fossil soil seen in the new cut on Elliott Street, Hamilton. These two views are taken looking north. On the south side of the street this soil is similarly well exposed. The age of this soil is problematical, but is probably St. George's. If it is of later date, it is the only case of so young a soil intercalated between eolianites in the Hamilton region. It is evident that considerable erosion had taken place before the overlying eolianite was deposited. Note the soil stains from above, resembling pockets, at the top of both views. By placing the upper view to the right of the lower a complete section of the overlying dune can be had.



1

2

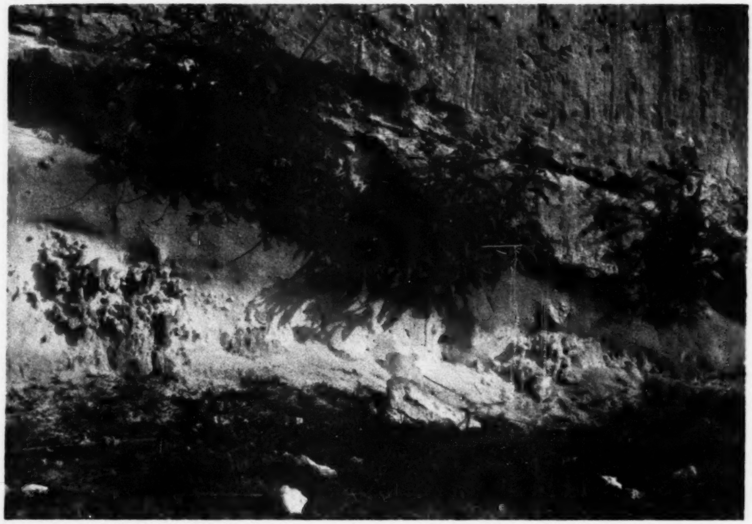
PLATE 5.

1. An exposure of the Harrington soil at Pitt's bay, near the Princess Hotel, just below the highway and about 5 feet above sea-level. This soil is about 18 inches thick at this point, and of a light-red color and has a few land mollusca, chiefly Poecilozonites, but usually the smaller varieties of this genus. This soil marks the end of the long period of soil formation, thought to be the equivalent of the long Yarmouth interglacial stage, or Harrington in this paper.

Locality 55.

2. There are two soils seen in this view, a lower red soil about 1 ft. thick, indicated by the collecting bag, and an upper soil about 3 ft. thick. The order of this section is as follows: some eolianite underneath the lower soil, well consolidated and showing that much erosion took place during the formation of the lower soil; the lower soil underlain by a soil base and this is followed by about 4 ft. of eolianite; the upper soil about 3 ft. thick with solution pockets at the bottom; and in places a soil base; and lying on this soil is the recent soil. More fossils were found in the upper soil than the lower, and in both cases they were of the smaller varities of the Poecilozonites genus as in the case of the Pitt's bay locality shown in 1, on this plate. The ages of these soils are problematical, but are considered to be Shore Hills-Harrington or St. George's.

Locality 95, on Victoria Street, near the corner of Court and Victoria Sts.



1

2

PLATE 6.

1. View of fossil soil on Mt. Royal. This soil is light red in color and from 4 to 5 ft. thick. It follows the grade of the hill closely north and south, disappearing on both sides beneath the surface. Fossils are scarce and when found are of the smaller varieties of the genus *Poecilozonites bermudensis*. There is a capping of northeastward dipping beds of eolianite on this soil with the usual 30° dips of beds on the leeward sides of dunes, showing that the sands came from the southwest and lie at the angle of repose, as is the case with almost all the eolianites on the south of the main island of Bermuda. Each successive eolianite-making stage extended the land farther south in this part of Bermuda. This soil may be of Signal Hill age.

Locality 111–12.

2. View taken at the top of Mt. Royal from a cut at right angles to the view in No. 1, of this plate, and looking east. The telegraph pole in both views is the same. The fossil soil may be seen dipping west towards the observer, under the eolianite, and across the street, the same soil may be seen again, with a thin capping of eolianite, and this latter surmounted by the conventional Bermuda wall. Note the 30° dip of the eolianite. This eolianite is composed of grains of crystalline limestone very well rounded.

Locality 111–12.

1

2

PLATE 7.

1. View looking east along the marine bench at McGall's bay. In the cliff appear 4 fossil soils, noted first by Clark in 1926. On the bench itself the writer found patches of the oldest soil, the Shore Hills, thus making 5 soils in all for this locality. With the exception of the uppermost soil, the McGall's soil, all these soils show evidence of considerable weathering, and the hill as it now stands is the resultant of eolianite and soil formations, covering the interval between the Shore Hills soil stage and the present time, or in terms of the Pleistocene, and according to the conclusions reached in this paper, the time between the Yarmouth and the present.

Localities 66–72.

2. View taken under the cliff at McGall's bay to show Harrington soil overlain by the windward beds of a dune of Pembroke eolianite, dipping about 12° to the east. Wind scour has eroded the soil beneath as can be noted on the right. The texture and fresh condition of this soil in many places would indicate that it is a soil of accretion to some extent, and that the lowering of the water level at the end of the Devonshire had exposed beds of fine material off shore to wind action. The indurated deep red soil, supposed to be the Shore Hills soil, was found under this Harrington soil in small patches not far from this spot. Another indurated red soil was found about 300 yds. west of this locality with the usual "palmetto holes" and this is presumably the same indurated red soil found at this locality. The limestone on which the red soil is found is without much doubt the Belmont marine limestone.

Locality 66.

1

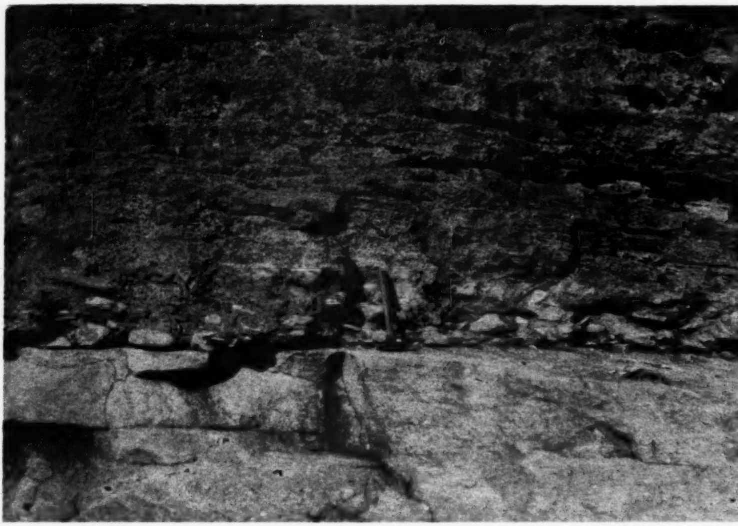
2

PLATE 8.

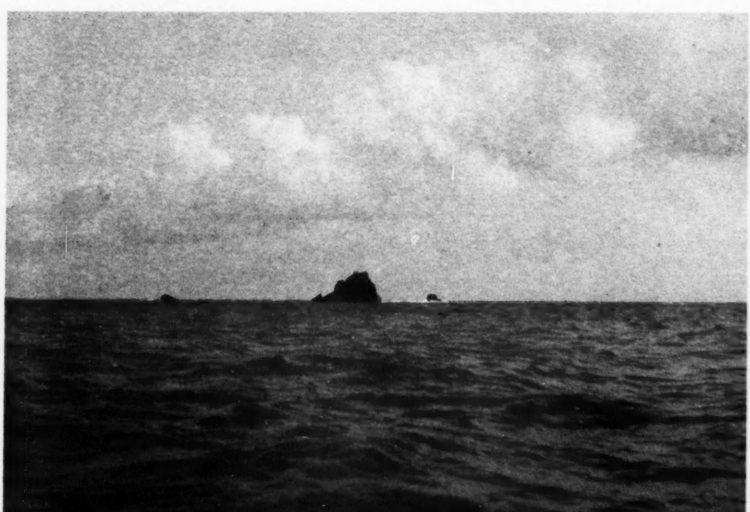
1. This view, taken at Devonshire bay, shows what the writer believes to be the Belmont marine formation, overlain by the Devonshire beach conglomerate and sandstone. The Shore Hills soil is absent and was probably washed away when the conglomerate was formed. At many places along the south shore, what Verrill calls "palmetto stumps" can be seen penetrating the Belmont formation. In the opinion of the writer and also of Professor Schuchert these "palmetto stumps" are nothing but solution holes caused in the development of soils, like those found in plate 2. At the Grape bay locality 146 this condition can be seen better than anywhere else. No one who has seen these solution holes in the Shore Hills soil at Grape bay can doubt the similar origin of all the "palmetto stumps." The Grape bay locality was not discovered until the plates were finished.

Locality 80.

2. A view of the Gurnet rocks, taken from a motor boat south of Castle Harbor. The Gurnet rocks, like north rock, are remnants of a former dune. The Gurnet rocks lie close to the southern edge of the lagoon, just as the north rock lies at the northern edge, and have a depth of water about them of from 2 to 3 fathoms. Suddenly the water deepens to 10 or more fathoms southward. At the close of the Wisconsin stage of the Pleistocene, it is evident that dunes lay close to the edge of the present outer reefs and irregularly over the present lagoon floor. With the return of the waters from the melting icecaps these dunes were partly submerged and almost entirely destroyed by wave action. The Gurnet rocks and the North rock remain as witnesses of this Wisconsin dune stage.



1



2

PLATE 9.

1. View taken at Hungry bay. The marine bench at the left is about 12 feet above sea-level. At the right under the cliff is an excavation made by laborers.

Locality 143.

2. A view of what might be called a fossil sea-cave just above horizontal marine sandstone. The cave is just above the excavation shown in No. 1 on this plate, but is not visible in No. 1. Loose blocks cemented together may be seen in the upper left part of this picture. At the lower left corner a pail may be seen which gives an idea of the scale. The floor of this cave has an altitude above sea-level of about 220 feet. Several feet above the cave is a fossil soil, the Harrington, which can be seen in the cliff as it rises from a point almost at sea-level.

Locality 133.

1

2

PLATE 10.

1. A view of the typical marine corrosion in the Belmont marine sandstone at Pink Beach. At the upper left is a corner of a stack of eolianite, the remnant of a former dune, which formed, and then later when the sea-level attained a height of about 15 feet higher than the present sea-level, the dune of eolianite was almost obliterated. Fossil soils are found about 100 feet north of the stack and the lowest rests on the Belmont formation. This lowest soil is absent between the stack and the Belmont, nor do the upper ones appear in the stack. It is evident that the eolianite of the stack is younger than the fossil soils, perhaps of Wisconsin age.

Locality 107.

2. An example of deep corrosion at the shore of Castle Harbour back of Walsingham House. The limestone seen is not in loose blocks but is part of the solid ledge. The much deeper corrosion in No. 2, as compared with that shown in No. 1, of this plate, would indicate that the uncovering of the Belmont marine sandstone in No. 1, is an event of no great antiquity geologically. The 15-foot recession of sea-level, advocated by Daly, may throw light on the history of the stack at Pink Beach and also on the deep weathering at Walsingham House, and may give a means of determining comparative time estimates.

1

2

PLATE 11.

1. A microphotograph of the reddish rock underlying the Shore Hills soil at Stokes point St .George's. This rock is full of much weathered eolianite grains and foraminifera. The Shore Hills soil lies on this rock and in solution pockets. The soil is overlain by the Devonshire marine formation. The reddish rock may be a phase of the Belmont formation, but if so it must have been exposed to the air to account for the much weathered grains of which it is composed. Marine forms and brecciated fragments of the red rock are mixed together at the bottom of the soil, while at the top, nothing but land mollusca are found. The problem which Stoke's Point presents has not been conclusively solved at this writing. Magnification in microphotograph about 20 diam. Microphotograph by E. C. Jeffrey. Locality 24.

2. A microphotograph of the Shore Hills soil at Hinson island, Hamilton harbor. The conditions in this soil are not so very different from those in the red rock of No. 1, on this plate. Weathering of the foraminifera and eolianite grains is marked. Magnification about 20 diam. Microphotograph by E. C. Jeffrey. Locality 105.

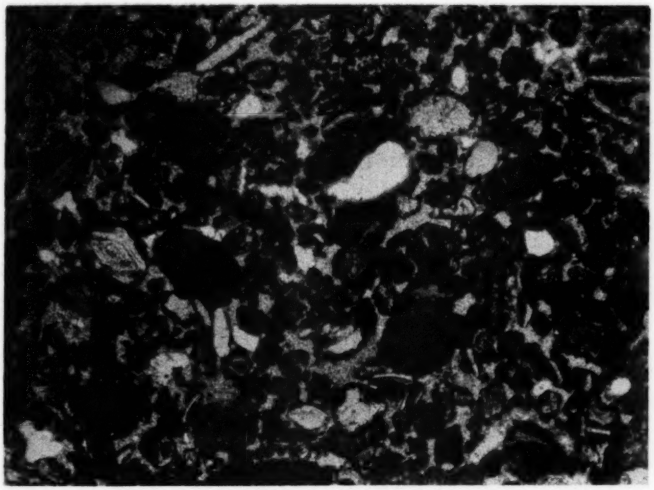


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PLATE 12.

Some of the more common land mollusca found in the fossil soils of Bermuda. After Verrill.

1. Poecilozonites dalli, × 1½.
2. Zonitoides bristoli, × 20.
3. Poecilozonites cupula, × 1.

4–5. Strobilops hubbardi, × 4.

6–7. Carychium bermudensis, Gul. × 13. Profile and front views.

8. Vertigo numellata, Gul. × 13.
9. Vertigo marki, Gul. × 13.

10–11. Euconulus turbinatus, Gul. × 8.

12–13. Thysanophora hypolepta, Pilsbury, much enlarged.

14–15. Poecilozonites circumfirmatus, Verrill, much enlarged.

16–17. Zonitoides minusculus, Binney enlarged.

18. Poecilozonites nelsoni, × 1.
19. Poecilozonites callosus, × 1.

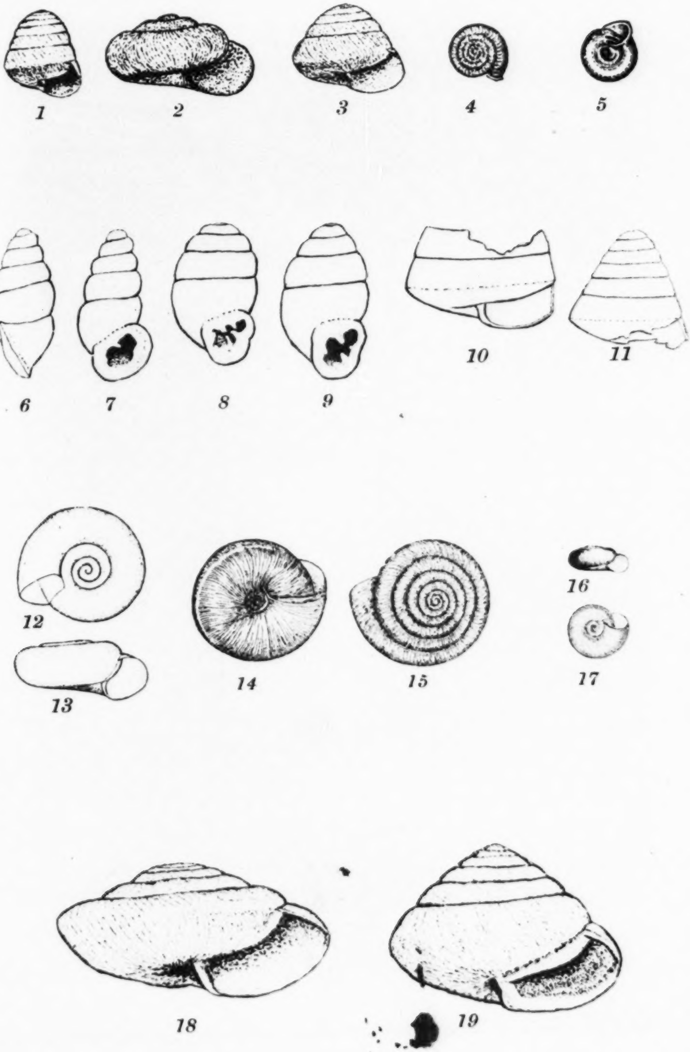
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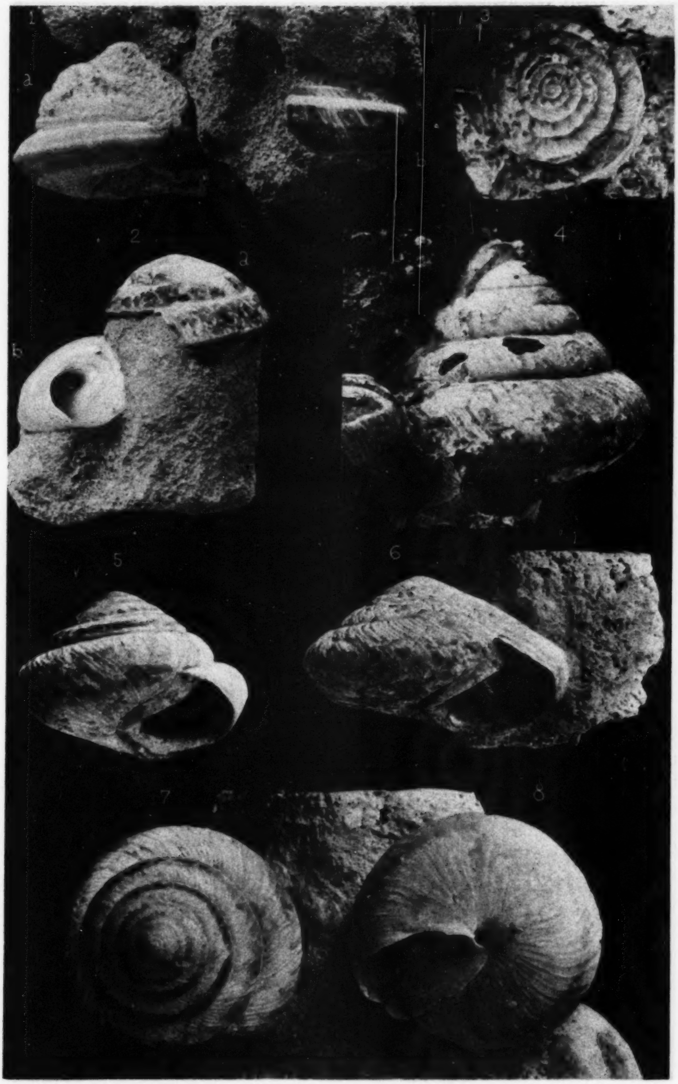
PLATE 13.

Some of the more important fossil land snails found in the fossil soils of Bermuda. *Poecilozonites nelsoni* is the most important fossil as an horizon marker so far discovered. It has never been found above the Harrington-Pembroke formations. It has been found by the writer in the Walsingham formation at the entrance of Crystal Cave, just inside the gate, and has been mentioned by Verrill as occurring in the Walsingham formation. Small varieties of *Poecilozonites bermudensis* are found more commonly in the Shore Hills and Harrington soils and the larger varieties, especially var. *zonatus*, are found in large quantities in the St. Georges, Signal Hill and McGall's soils. As the paleontology of the soils is only partly done, little more can be said at present.

1–2. Poecilozonites bermudensis, var. zonatus, Nat. size.
3. Poecilozonites reinianus var. antiquus, $\times 2\frac{1}{2}$
4. Poecilozonites nelsoni, var. concoides, Nat. size.
5–6. Poecilozonites nelsoni, var. callosus, Nat. size.
7–8. Poecilozonites nelsoni, var. nelsoni, Nat. size.

Photographed from Verrill.


1
a
3
b
2
a
b
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6
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8

TABLE V. PETROLOGY OF

	Formation	Locality	Color	Percentage of insoluble coarser than silt	Quartz	Perovskite	Pyroxene	Magnetite	Orthoclase	Volcanic glass
	EOLIANITES									
1	Southampton	Quarry south of Mt. Royal	White	0.0004	36	18	34		6	tr
2	?	Hamilton	White	0.002	48			21		
3	?	?	White	0.0006	13	18	9		10	50
4	?	?	White	0.0004	45	20	15	20		
75	Southampton	McGall's Bay	White	0.001	90	tr		5		[illegible]
68	Somerset	McGall's Bay	Flesh	0.001	30	35			30	[illegible]
67	Warwick	McGall's Bay	White	0.0005	20				60	
24	Hamilton	McGall's Bay	Gray	0.001	20	5	5		60	
69	Walsingham	McGall's Bay	White	0.0005	30	40	30			
	SOILS									
x	Shore Hills	Arthur Haycock House, Walsingham	Red	1.25	40	51	tr	2	tr	
9	Shore Hills	Paynters Vale	Red	0.5	19	38	2	24	tr	
6	Recent	Spanish Rock	Gray	0.0003	10	80				
80	Harrington	Devonshire Bay	White	0.001	50		50			
81	Harrington	Devonshire Bay	Pink	0.01	9	25	40	5	18	
79	St. George's	Devonshire Bay	Red	0.005	20	25	10	45		
80	Signal Hill	Devonshire Bay	Pink	0.001		33	67			
107	Shore Hills	Pink Beach	Red	0.1	20	20	20	20		tr
143	Harrington	Hungry Bay	White	0.005	50	25	25			
143	Harrington	Hungry Bay	White	0.01	30	tr	40			
143	Harrington	Hungry Bay	White	0.002	30	30	30			
146	Shore Hills	Grape Bay	Red	0.05	20	20	50	9	tr	
155	Signal Hill	Simmons Beach	Gray	0.001	50		50			
5	Signal Hill	St. George's	Pink	0.001		25	50	25		
2	Signal Hill	St. George's	Pink	0.005	20	40	40			
[illegible]	St. George's	St. George's	Red	0.18	10	25	5	55		

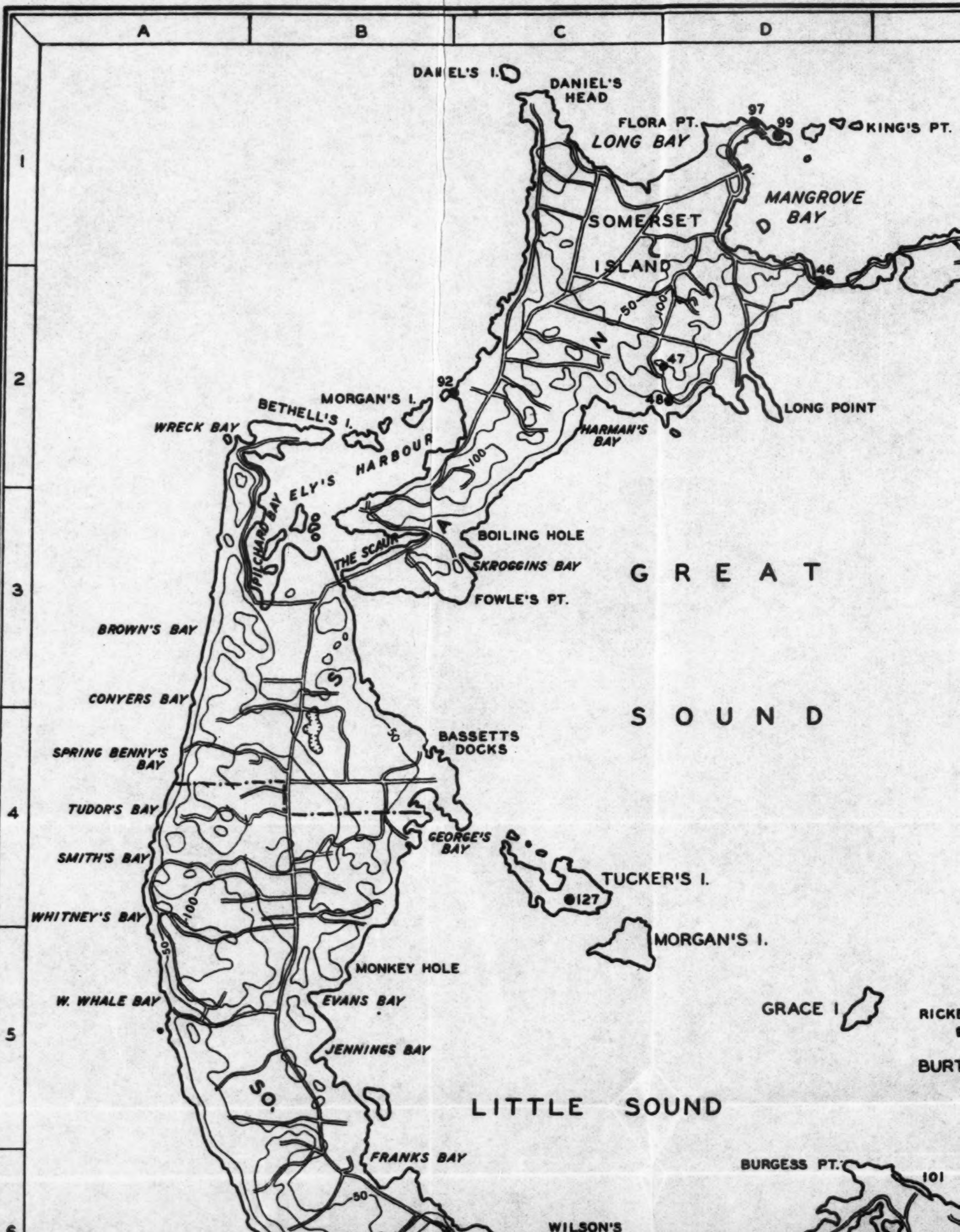
OF EOLIANITES AND SOILS.

Volcanic glass	Titanite	Zircon	Rutile	Brown garnet	Red garnet	Biotite	Hornblende	Hydrargillite (?)	Miscellaneous	Size	Notes
tr				6						Up to 1 min.	
								31		0.05 to 0.6 mm.	
50?										Up to 1 mm.	
5										Most less than 0.1 mm.; some 0.5 mm.	
?			?	5							
				20							
	tr				10				Chlorite		
										1 mm.	
	2	tr	1	1	tr				Tourmaline 1% Epidote 2%		quartz rounded
	7	tr	tr	6			tr		Muscovite tr Epidote 4%		
								10			
											2 grains
	2						1				
										Up to 2 mm.	10 grains
											3 grains
tr	tr			20						0.5 mm.	
											quartz corroded
	30	tr									
	10				tr						
	1				tr						
											4 grains
											quartz etched 17 grains
	5										

6	Recent	Spanish Rock	Gray	0.0003	10	80			
80	Harrington	Devonshire Bay	White	0.001	50		50		
81	Harrington	Devonshire Bay	Pink	0.01	9	25	40	5	1
79	St. George's	Devonshire Bay	Red	0.005	20	25	10	45	
80	Signal Hill	Devonshire Bay	Pink	0.001		33	67		
107	Shore Hills	Pink Beach	Red	0.1	20	20	20	20	
143	Harrington	Hungry Bay	White	0.005	50	25	25		
143	Harrington	Hungry Bay	White	0.01	30	tr	40		
143	Harrington	Hungry Bay	White	0.002	30	30	30		
146	Shore Hills	Grape Bay	Red	0.05	20	20	50	9	t
155	Signal Hill	Simmons Beach	Gray	0.001	50		50		
5	Signal Hill	St. George's	Pink	0.001		25	50	25	
2	Signal Hill	St. George's	Pink	0.005	20	40	40		
2	St George's	St. George's	Red	0.13	10	25	5	55	
1	St. George's	St. George's	Pink	0.05	10	40	50		
1	St. George's	St. George's	Deep-red	0.2	10	28	46	10	
1	St. George's	St. George's	Light Red	0.03	3	10	70	14	3
45	Harrington	St. George's	White	0.003		25	75		
164	Shore Hills	St. George's	Red	4.3	17	67	3	3	tr
7	Signal Hill	St. George's	Pink	0.01	25	25	25	25	
98	St. George's ?	Elliott Street, Hamilton	Red		87	2	4		
98	St. George's ?	Hamilton	Red	0.08	20	36	31		5
98	St. George's ?	Hamilton	Mottled Pink	0.001	55	tr		tr	
102	Shore Hills	Inverurie	Pink	0.1	77	18		3	
37	Shore Hills	Belmont	Red	0.1	100				
111	Signal Hill	Mt. Royal	Pink	0.001	58	22		10	10
105	Shore Hills	Hinson Island	Pink	0.003	90		10		
75	McGall's	McGall's Bay	Pink	0.02	40	6	6	4	6
68	Signal Hill	McGall's Bay	Pale Pink	0.001	20	3	70		tr
67	St. George's	McGall's Bay	Red	0.2	3	30	42	10	12
67	St. George's	McGall's Bay	Pink	0.01	50	10	15		
23	St. George's	McGall's Bay	Pink	0.02	12	2	2		83
66	Harrington	McGall's Bay	White	0.002	25	25	25		5
66	Harrington	McGall's Bay	White	0.001	60				
69	Shore Hills	McGall's Bay	Pink	0.02	7	46	23		
69	Shore Hills	McGall's Bay	Deep-red	0.05	40	40	10		5

												2 grains
18		2						1				
											Up to 2 mm.	10 grains
												3 grains
	tr	tr			20						0.5 mm.	
												quartz corroded
		30	tr									
		10				tr						
tr		1				tr						
												4 grains
												quartz etched 17 grains
		5										
	tr									Chlorite tr		
1		5										
3											Up to 2 mm.	30 grains
										Epidote tr		
tr		4	tr			2				Epidote 2% Corundum (?) tr Leucoxene 2%		
												4 grains
	5		1			1				Spinel tr		
5	4	2			2							
	45					?						
			1							Cyanite ½% Staurolite ½%		
											0.5 to 3 mm.	Sub-angular
10			tr								½ mm.	
6	38											
tr		tr	tr		?	tr	3	tr		Plagioclase tr	1 to 2 mm.	
12		3										
										Plagioclase 25%		14 grains
83						1	tr				0.1 to 1.0 mm.	
5										Plagioclase 20%		
	40											
		1			20	2				Epidote 1%		
5					5						½ mm.	

Map to accompany "Bermuda During the Ice Age" Proc. Amer. Acad. Arts and Sciences, Vol. 66, No. 11, N



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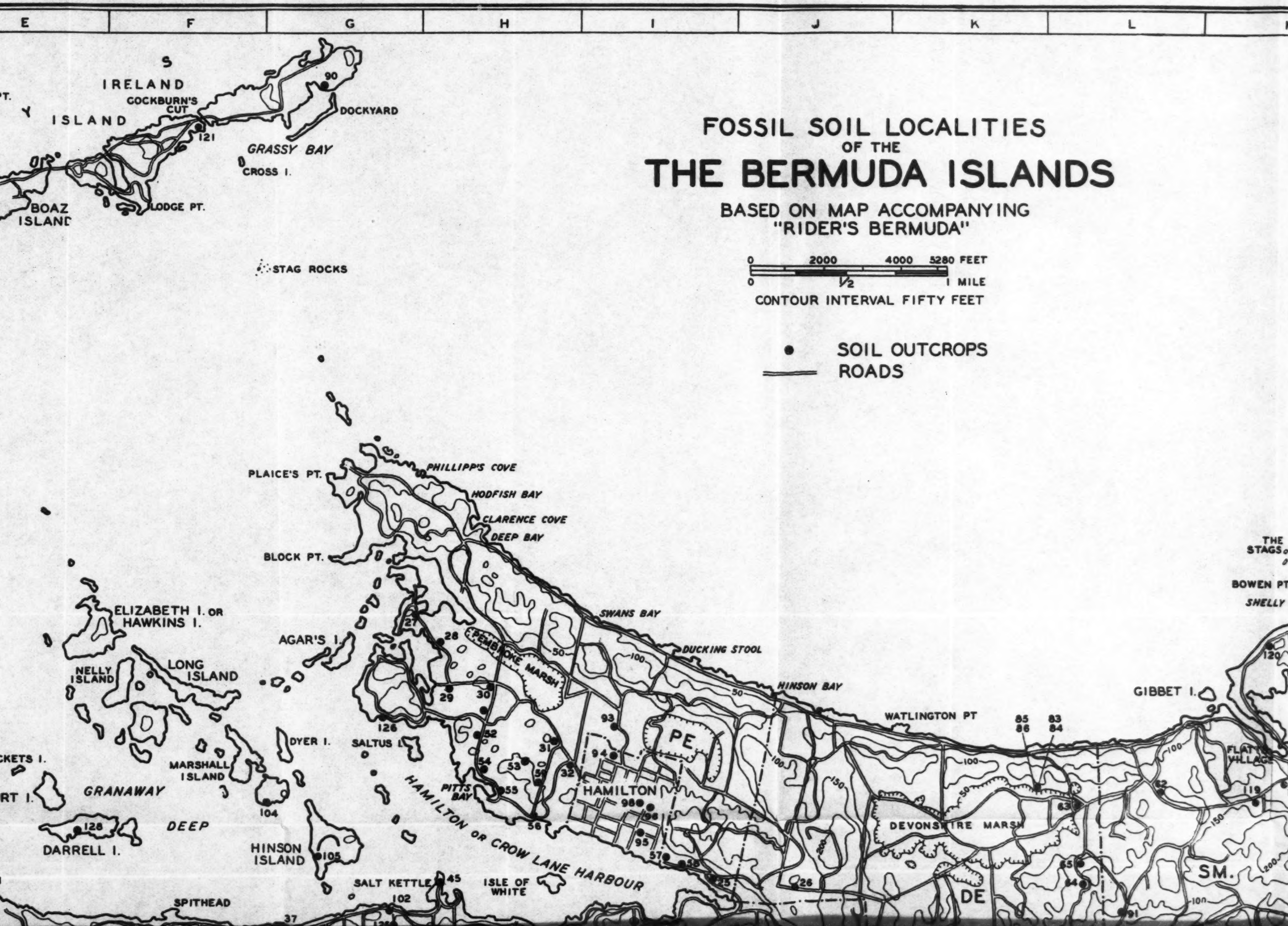
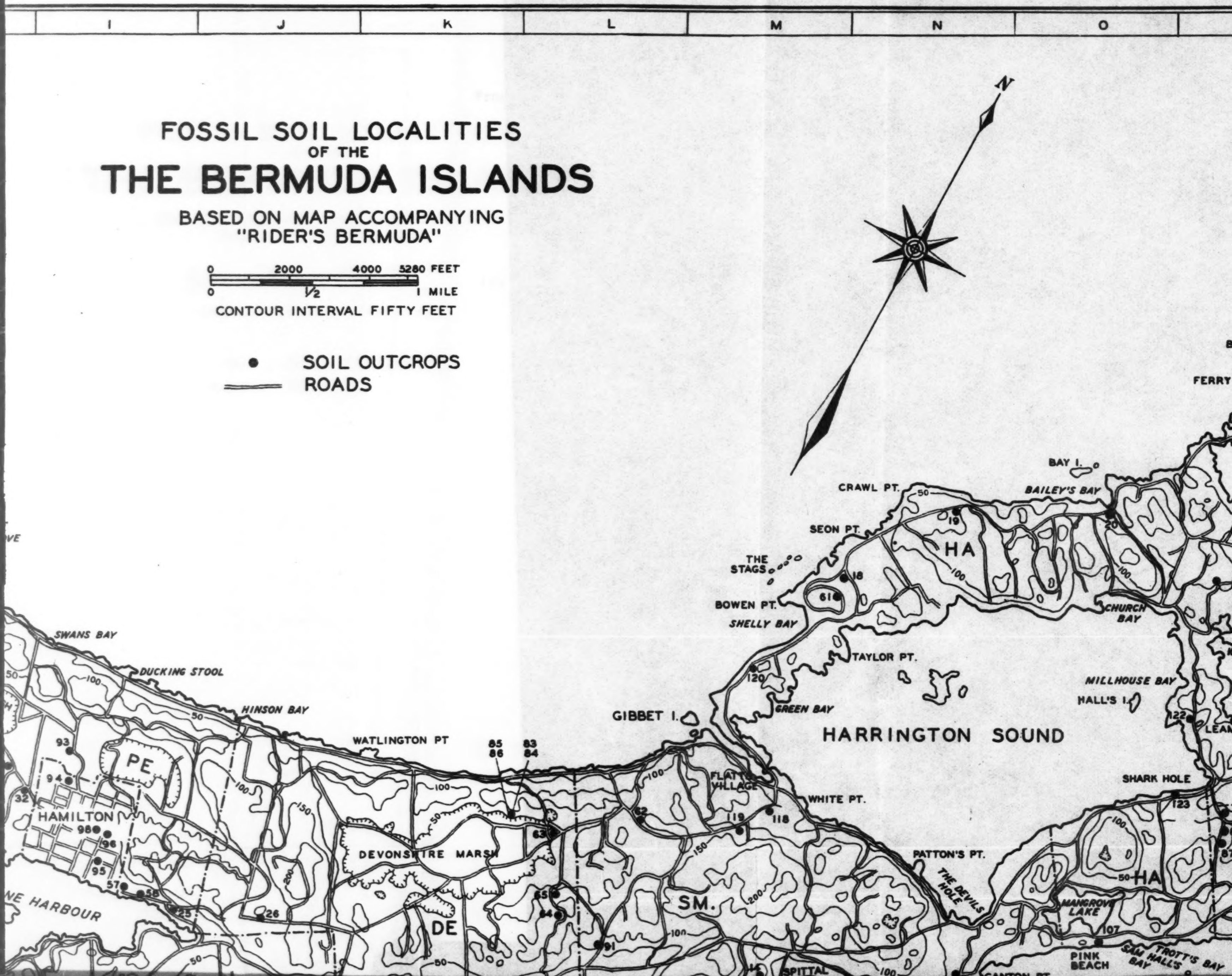
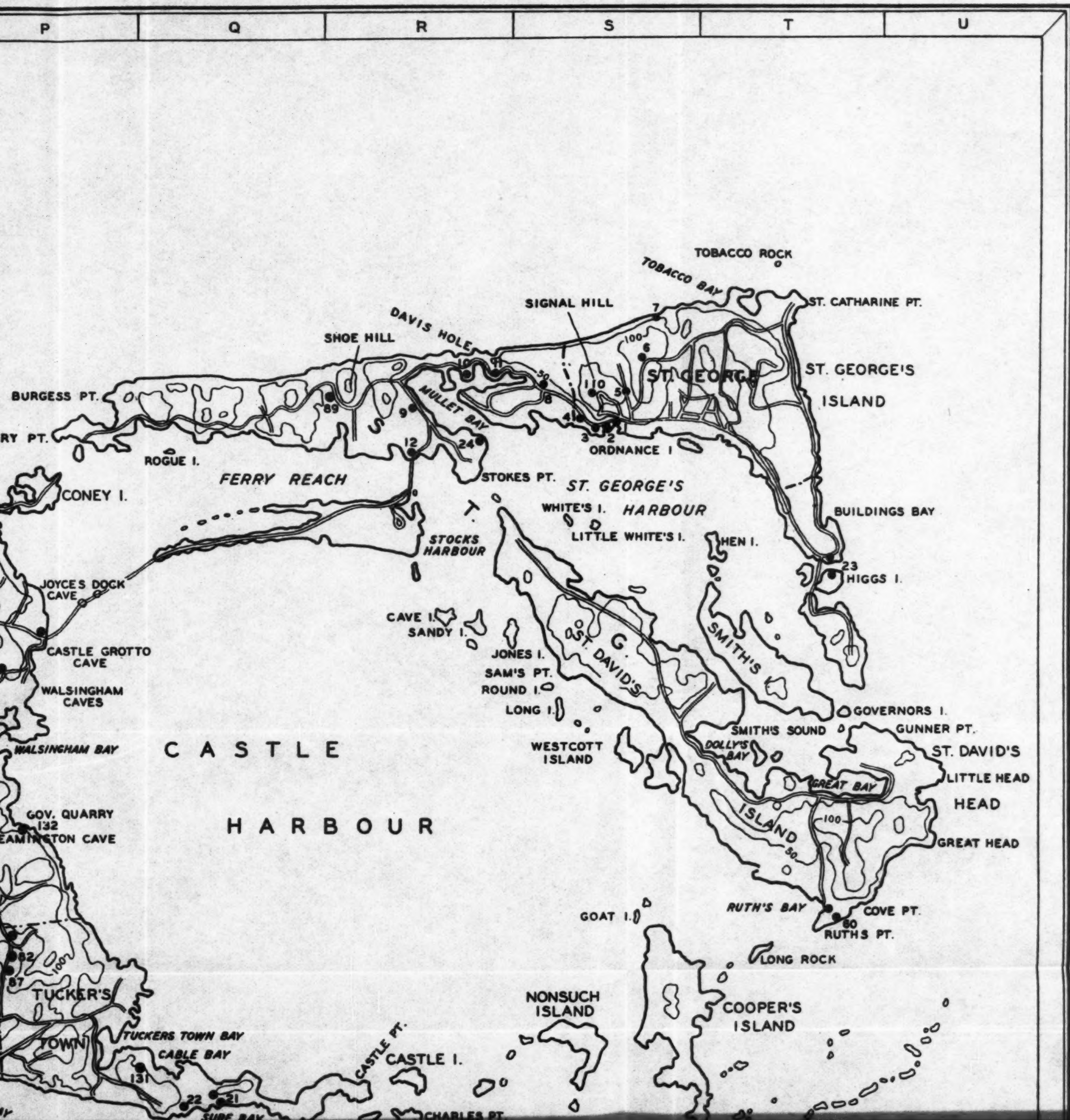



FOSSIL SOIL LOCALITIES
OF THE
THE BERMUDA ISLANDS
BASED ON MAP ACCOMPANYING
"RIDER'S BERMUDA"
0 2000 4000 5280 FEET
0 1/2 1 MILE
CONTOUR INTERVAL FIFTY FEET
SOIL OUTCROPS
ROADS
I
J
K
L
M
N
O
N
BAY I.
CRAWL PT.
BAILEY'S BAY
SEON PT.
HA
THE STAGS
BOWEN PT.
SHELLY BAY
CHURCH BAY
TAYLOR PT.
MILLHOUSE BAY
HALL'S I.
GIBBET I.
GREEN BAY
HARRINGTON SOUND
SWANS BAY
DUCKING STOOL
HINSON BAY
WATLINGTON PT
PE
HAMILTON
FLATTS VILLAGE
WHITE PT.
SHARK HOLE
DEVONSHIRE MARSH
PATTON'S PT.
THE DEVILS HOLE
MANGROVE LAKE
SM.
DE
HA
PINK BEACH
SAM HALL'S BAY
TROTT'S BAY
SPITTAL
CANTON PT.
FERRY
NE HARBOUR


P
Q
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TOBACCO ROCK
TOBACCO BAY
ST. CATHARINE PT.
SIGNAL HILL
DAVIS HOLE
SHOE HILL
ST. GEORGE
ST. GEORGE'S
ISLAND
BURGESS PT.
MULLET BAY
ORDNANCE I.
ROGUE I.
FERRY REACH
STOKES PT.
ST. GEORGE'S
HARBOUR
CONEY I.
WHITE'S I.
LITTLE WHITE'S I.
BUILDINGS BAY
STOCKS
HARBOUR
HEN I.
HIGGS I.
JOYCES DOCK
CAVE
CAVE I.
SANDY I.
CASTLE GROTTO
CAVE
JONES I.
SAM'S PT.
ROUND I.
LONG I.
ST. DAVID'S
SMITH'S
WALSINGHAM
CAVES
GOVERNORS I.
SMITH'S SOUND
GUNNER PT.
WESTCOTT
ISLAND
DOLLY'S
BAY
ST. DAVID'S
LITTLE HEAD
HEAD
WALSINGHAM BAY
CASTLE
GREAT BAY
ISLAND
GOV. QUARRY
HARBOUR
GREAT HEAD
RUTH'S BAY
COVE PT.
GOAT I.
RUTHS PT.
LONG ROCK
TUCKER'S
NONSUCH
ISLAND
COOPER'S
ISLAND
TOWN
TUCKERS TOWN BAY
CABLE BAY
CASTLE PT.
CASTLE I.
SURF BAY
CHARLES PT.

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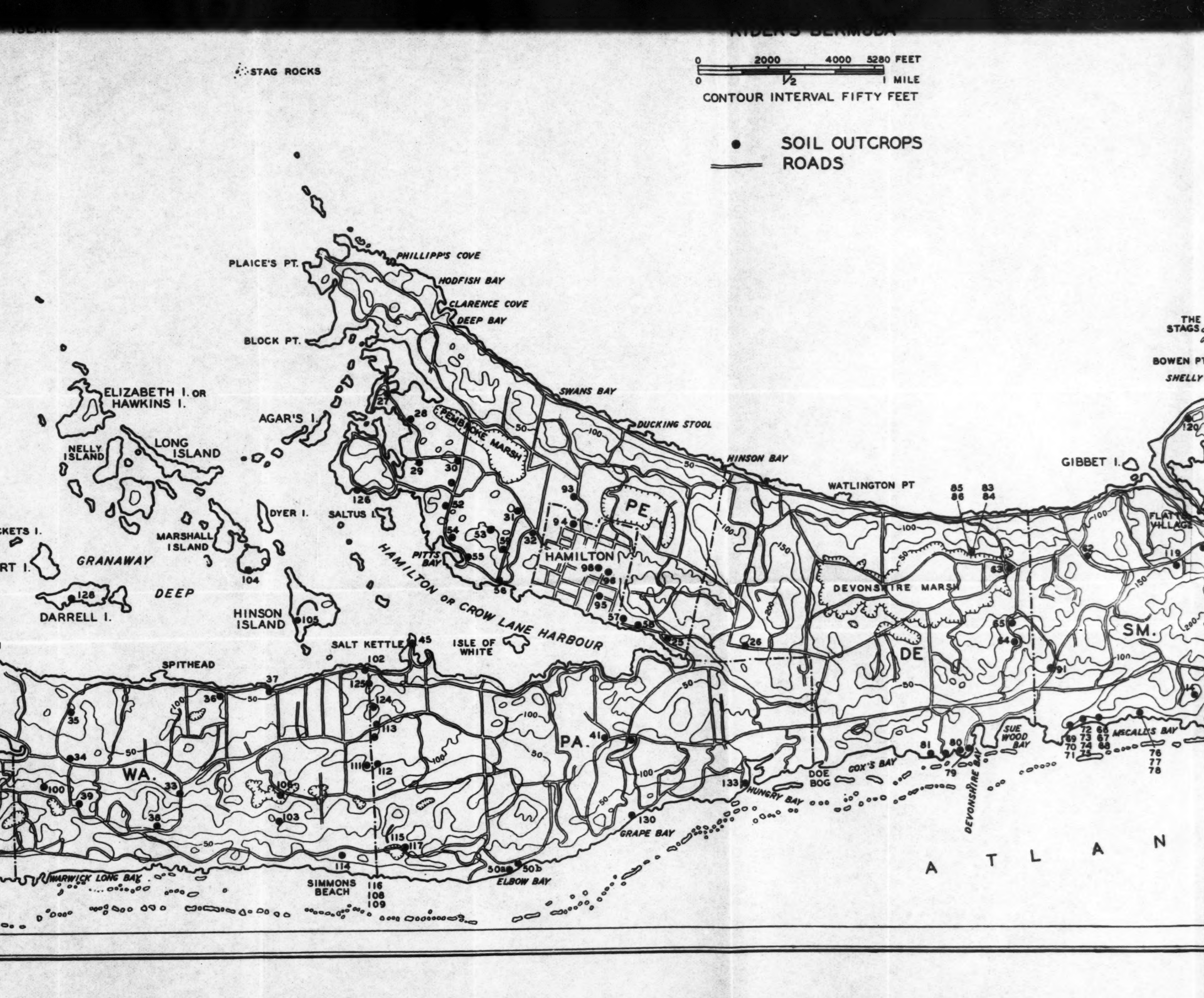
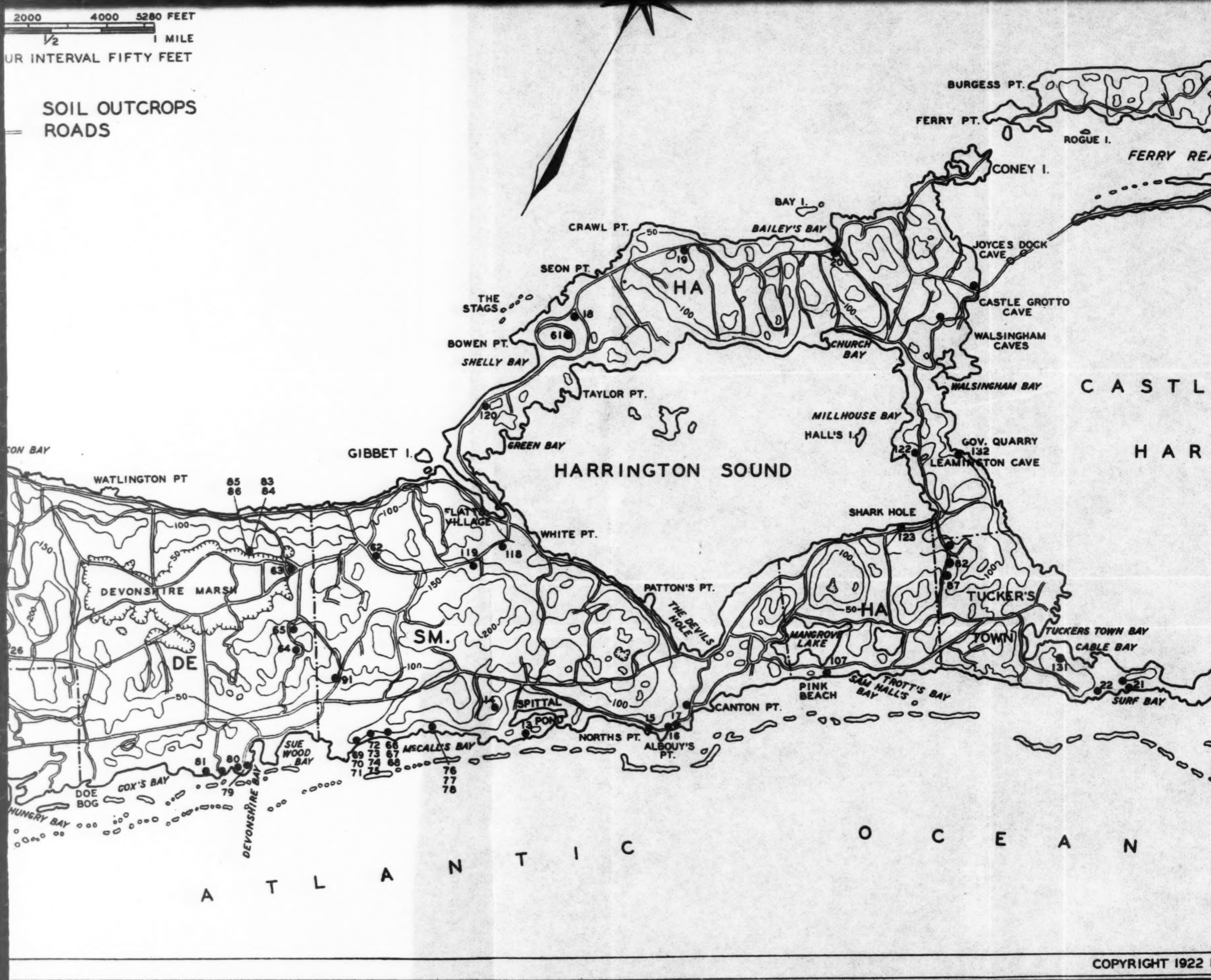
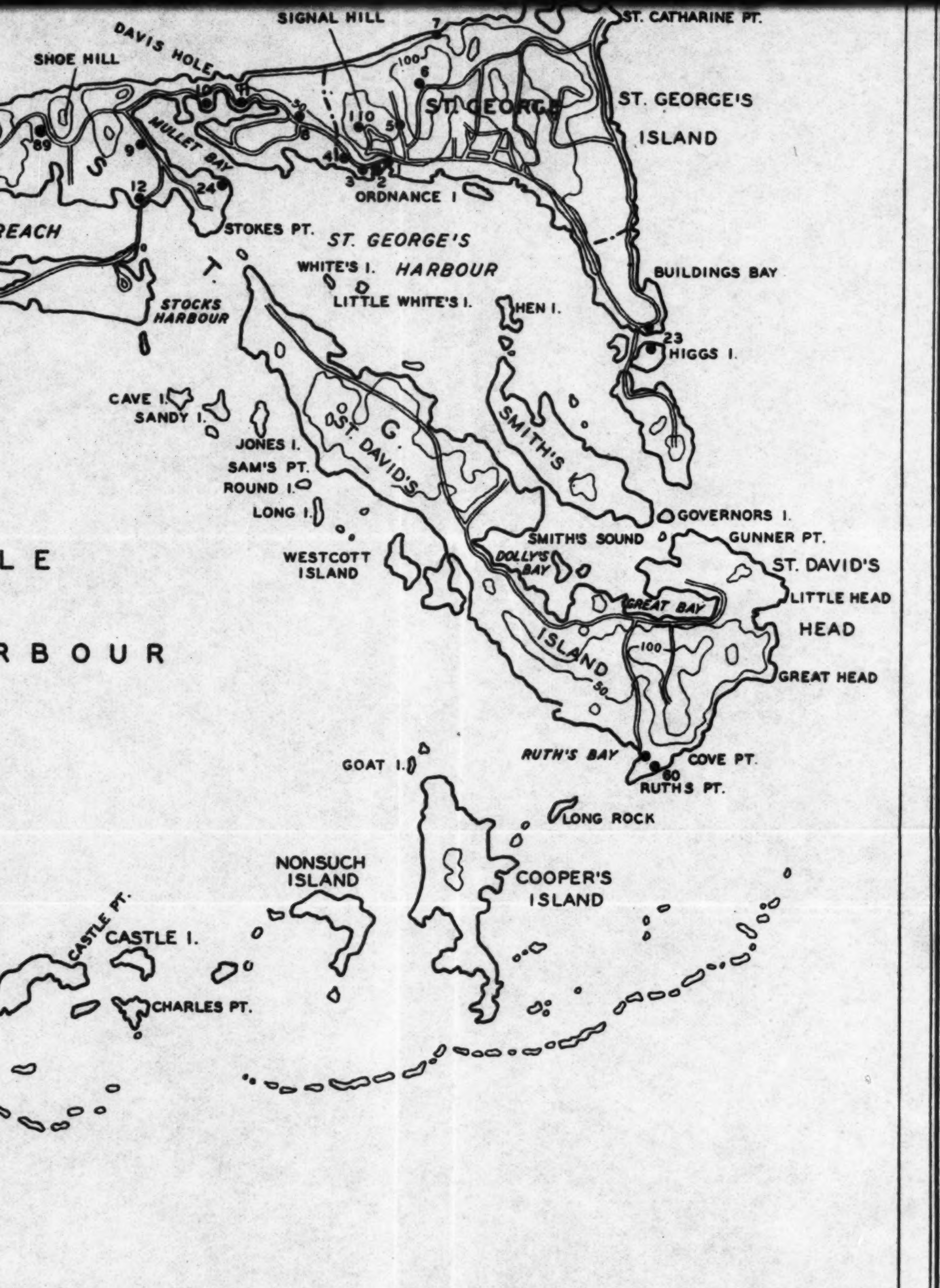
7
MORGAN'S I.
92
BETHELL'S I.
WRECK BAY
ELY'S HARBOUR
PILCHARD BAY
HARMAN'S BAY
LONG POINT
47
48
100
50
BOILING HOLE
THE SCAUR
SKROGGINS BAY
FOWLE'S PT.
GREAT
SOUND
BROWN'S BAY
CONYERS BAY
BASSETTS DOCKS
SPRING BENNY'S BAY
TUDOR'S BAY
GEORGE'S BAY
SMITH'S BAY
TUCKER'S I.
127
WHITNEY'S BAY
MORGAN'S I.
MONKEY HOLE
W. WHALE BAY
EVANS BAY
GRACE I.
JENNINGS BAY
SO.
LITTLE SOUND
FRANKS BAY
BURGESS PT.
101
WILSON'S I.
129
HUNT'S I.
PEROT'S
RIDDLE'S BAY
44
43
JEWS BAY
HIGH POINT
TURTLE BAY
CHURCH BAY
42
86
40
150
200
GIBBS HILL
49
51
CHRISTIAN BAY
BOAT BAY
SINKY BAY
CROSS BAY
E. WHALE BAY
HORSESHOE



STAG ROCKS
0 2000 4000 5280 FEET
0 1/2 1 MILE
CONTOUR INTERVAL FIFTY FEET
SOIL OUTCROPS
ROADS
PLAICE'S PT.
PHILLIPP'S COVE
HODFISH BAY
CLARENCE COVE
DEEP BAY
BLOCK PT.
SWANS BAY
ELIZABETH I. OR HAWKINS I.
AGAR'S I.
PEMBROKE MARSH
DUCKING STOOL
NELLY ISLAND
LONG ISLAND
HINSON BAY
GIBBET I.
WATLINGTON PT
THE STAGS
BOWEN PT.
DYER I.
SALTUS I.
MARSHALL ISLAND
GRANAWAY
DEEP
DARRELL I.
HINSON ISLAND
PITTS BAY
HAMILTON
HAMILTON OR CROW LANE HARBOUR
PE
DEVONSHIRE MARSH
FLATTS VILLAGE
SM.
DE
SALT KETTLE
ISLE OF WHITE
SPITHEAD
WA.
PA.
SUE WOOD BAY
MECALL'S BAY
DOE BOG
COX'S BAY
HUNGRY BAY
DEVONSHIRE BAY
GRAPE BAY
ELBOW BAY
SIMMONS BEACH
WARWICK LONG BAY
A T L A N


2000 4000 5280 FEET
1/2 1 MILE
UR INTERVAL FIFTY FEET
SOIL OUTCROPS
ROADS
BURGESS PT.
FERRY PT.
ROGUE I.
FERRY REA
CONEY I.
BAY I.
CRAWL PT.
BAILEY'S BAY
JOYCES DOCK CAVE
SEON PT.
HA
CASTLE GROTTO CAVE
THE STAGS
BOWEN PT.
SHELLY BAY
CHURCH BAY
WALSINGHAM CAVES
WALSINGHAM BAY
TAYLOR PT.
C A S T L
MILLHOUSE BAY
HALL'S I.
GREEN BAY
GOV. QUARRY
LEAMINGTON CAVE
GIBBET I.
HARRINGTON SOUND
H A R
SON BAY
WATLINGTON PT
FLATTS VILLAGE
WHITE PT.
SHARK HOLE
DEVONSHIRE MARSH
PATTON'S PT.
THE DEVILS HOLE
TUCKER'S TOWN
SM.
DE
MANGROVE LAKE
TUCKERS TOWN BAY
CABLE BAY
SPITTAL POND
PINK BEACH
SAM HALL'S BAY
TROTT'S BAY
CANTON PT.
SURF BAY
NORTHS PT.
ALBOUY'S PT.
SUE WOOD BAY
MCALL'S BAY
COX'S BAY
DOE BOG
DEVONSHIRE BAY
HUNGRY BAY
A T L A N T I C O C E A N


SIGNAL HILL
ST. CATHARINE PT.
DAVIS HOLE
SHOE HILL
MULLET BAY
ST. GEORGE
ST. GEORGE'S
ISLAND
ORDNANCE I
REACH
STOKES PT.
ST. GEORGE'S
HARBOUR
WHITE'S I.
LITTLE WHITE'S I.
HEN I.
BUILDINGS BAY
HIGGS I.
STOCKS
HARBOUR
CAVE I.
SANDY I.
JONES I.
SAM'S PT.
ROUND I.
LONG I.
ST. DAVID'S
SMITH'S
GOVERNORS I.
SMITH'S SOUND
GUNNER PT.
WESTCOTT
ISLAND
DOLLY'S
BAY
ST. DAVID'S
LITTLE HEAD
HEAD
GREAT BAY
ISLAND
GREAT HEAD
L E
R B O U R
RUTH'S BAY
COVE PT.
RUTHS PT.
GOAT I.
LONG ROCK
NONSUCH
ISLAND
COOPER'S
ISLAND
CASTLE PT.
CASTLE I.
CHARLES PT.